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Science
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TRANSACTIONS

OF

THE ACADEMY OF SCIENCE OF ST. LOUIS.

VOL. XXII.

JANUARY, 1913, TO DECEMBER, 1913.

PUBLISHED UNDER DIRECTION OF THE COUNCIL.

ST. LOUIS.
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LIST OF OFFICERS, 1913.

President	Edmund A. Engler.
First Vice President	Francis E. Nipher.
Second Vice President	Arthur E. Ewing.
Recording Secretary	J. A. Drushel.
Corresponding Secretary	George O. James.
Treasurer	H. E. Wiedemann.
Librarian	Wm. L. R. Gifford.
Curators	Julius Hurter. Philip Rau. Hermann von Schrenk.
Directors	Adolf Alt. H. M. Whelpley.

MEMBERS.

1. Patrons.

Bixby, William Keeney.....Kingshighway and Lindell Bls.
Eliot, Henry Ware.....4446 Westminster Pl.
†Harrison, Edwin.....
Mallinckrodt, Edward.....26 Vandeventer Pl.
McMillan, Mrs. Eliza.....25 Portland Pl.
McMillan, William Northrop...Century Bldg.

2. Honorary Members.

Arrhenius, Prof. Svante.....University of Stockholm, Sweden.
Bahlsen, Prof. Dr. Leopold....University of Berlin, Germany.
Kitasato, Prof. Shibasaburo....University of Tokyo, Japan.
Lewald, Geh. Oberreg. Rath Theodor .....Berlin, Germany.
Limburg, Stirum, Graf.....Berlin, Germany.
Orth, Geh. Rath Dr. Johann...University of Berlin, Germany.
Ostwald, Prof. Wilhelm.....University of Leipzig, Germany.
Ramsay, Sir William.....Royal Institute, London, England.
Rutherford, Prof. Ernest.....University of Manchester, England.
Springer, Frank.....U. S. National Museum, Washington, D. C.
Trelease, William.....University of Illinois, Urbana, Ill.
Waldeyer, Geh. Rath Prof. Dr. Wilhelm .....University of Berlin, Germany.
Wassermann, Prof. Dr. A.....University of Berlin, Germany.
Wittmack, Geh. Reg. Rath Prof. Dr. L. .....University of Berlin, Germany.

† Deceased.

3. Active Members.

Alleman, Gellert[1]..... Swarthmore College, Swarthmore, Pa.
Allen, George L..... 26 Westmoreland Pl.
Alt, Adolf..... 316 Metropolitan Bldg.
Altheimer, Benjamin ..... Melrose Apartments.
Ameiss, F. C..... 4908d Euclid Terrace.

Baker, Robert H.[1]..... University of Missouri, Columbia, Mo.
Barck, Carl..... Humboldt Bldg.
Barnard, George D..... Vandeventer and Laclede Aves.
Baumgarten, Walter..... Humboldt Bldg.
Beckwith, Thomas[1]..... Charleston, Mo.
Beede, J. W.[1]..... Wall and Atwater Sts., Bloomington, Ind.
Bemis, S. A..... Fourth and Poplar Sts.
Bessey, Charles Edwin[1]..... University of Nebraska, Lincoln, Neb.
Blair, V. P..... Metropolitan Bldg.
Blankinship, Joseph William[1].. 2525 Hilgard Ave., Berkeley, Cal.
Blewett, Ben ..... Ninth and Locust Sts.
Bock, George W..... 2904 Allen Ave.
Borgmeyer, Charles J..... St. Louis University.
Bostwick, Arthur E..... 70 Vandeventer Pl.
Brandenburger, W. A.[1]..... 312 Inverness Bldg., Sacramento, Cal.
Branner, J. C.[1]..... Stanford University, Cal.
Brennan, Martin S..... 6304 Minnesota Ave.
Brimmer, George G..... 6900 Michigan Ave.
Britton, F. H.[1]..... Kirkwood, Mo.
Brock, James E..... Mississippi Valley Trust Co.
Brookings, Robert S..... 6510 Ellenwood Ave.
Brown, Daniel S.[1]..... Brownhurst, Kirkwood, Mo.
Buehler, H. A.[1]..... Rolla, Mo.
Burg, William ..... 4439 Washington Boul.
Busch, Aug. A..... Busch Pl.
Bush, Benjamin Franklin[1]..... Courtney, Mo.
Butler, William M..... Yeatman High School.

[1] Non-resident.

Cale, George W., Jr.....12 Lennox Pl.
Campbell, James A.....Mermod Jaccard Bldg.
Carleton, Murray.....1135 Washington Ave.
Carpenter, George O.....12 Portland Pl.
Carr, Peyton T.....62 Vandeventer Pl.
Carver, George Washington[1]...Tuskegee, Ala.
Caspari, Charles E.....4060 Westminster Pl.
Catlin, Daniel.....Security Bldg.
Chambers, C. O.[1].....University of Cincinnati, Cincinnati, O.
Chappell, W. G.....501 Clara Ave.
Chenery, Winthrop Holt.....Washington University.
Clarke, Enos[1].....Kirkwood, Mo.
Clopton, Malvern B.....Humboldt Bldg.
Colnon, R. S.....506 Merchants' Laclede Bldg.
Conzelman, Theophilus.....5260 Washington Boul.
Cook, Abraham.....4208 Pine St.
Cook, Francis E.....5510 Cates Ave.
Cook, Isaac T.....Chemical Bldg.
Cook, Jerome E.....4254 Lindell Boul.
Cramer, Gustav.....Care Cramer Dry Plate Co.
Crawford, Hanford.....4442 Lindell Boul.
Crecelius, Elyse C.....1110 Dillon St.
Curley, Francis E. A.....6143 Berlin Ave.
Curtis, William S.....Washington University.

Dameron, Edward Caswell[1]....Clarksville, Mo.
Danforth, Charles H.....Washington University, Medical Department.
Davis, H. N.....56 Vandeventer Pl.
Davis, John D.....Third National Bank Bldg.
Dewey, Lyster H.[1].....4612 Ninth St., N. W., Washington, D. C.
Diehm, Ferdinand.....6175 Kingsbury Boul.
Doan, George P.....42 Portland Pl.
Dock, George.....Washington University, Medical Department.
Dorsett, Walter B.....Wall Bldg.
Dougan, Lewis M.....3955 Botanical Ave.
Drosten, F. W.....3521 Victor St.
Drushel, J. A.....Teachers' College.

Duggar, Benjamin M.....Missouri Botanical Garden.
Duncker, Charles H.....3636 Page Ave.

Ebeling, A. W.[1].....Warrenton, Mo.
Eberle, E. G.[1].....416 Jackson St., Dallas, Texas.
Eilers, Roy M.....Central National Bank Bldg.
Eimbeck, August F.[1].....New Haven, Mo.
Eliot, Edward C.....5468 Maple Ave.
Emerson, John B.....Syndicate Trust Bldg.
Emmel, Victor E.....Washington University, Medical Department.
Engler, Edmund Arthur.....Washington University.
Ericson, Eric John.....1420 Clara Ave.
Erker, Adolph P.....608 Olive St.
Espenschied, Charles .....3500 Washington Ave.
Evers, Edward .....1861 North Market St.
Ewers, A. F.....3411 Pestalozzi St.
Ewing, Arthur E.....5956 Cabanne Pl.

Fawcett, H. S.[1].....Whittier, Cal.
Fischel, Walter .....5284 Westminster Pl.
Fischel, Washington E.....Humboldt Bldg.
Fish, E. R.....2449 E. Marcus Ave.
Floyd, B. F.[1].....Gainesville, Fla.
Fordyce, John R.[1].....2223 Louisiana St., Little Rock, Ark.
Fordyce, S. W.....21 Washington Terrace.
French, George Hazen[1].....Carbondale, Ill.
Frerichs, Frederick W.....4320 Washington Boul.
Frick, John Henry[1].....Warrenton, Mo.
Fry, Frank R.....4609 McPherson Ave.
Funkhouser, Robert Monroe...4354 Olive St.

Garman, Harrison[1] .....Lexington, Ky.
Gecks, Frank .....3453 Magnolia Ave.
Geitz, H. A.[1].....17 West End Ave., Rockaway Park, Long Island, N. Y.
Gifford, William L. R.....Mercantile Library.
Gill, Charles M.....Teachers' College.
Gillette, C. P.[1].....Fort Collins, Colo.
Glasgow, Frank A.....3894 Washington Ave.

Goldstein, Max A.....3858 Westminster Pl.
Goltra, Edward F.....4416 Lindell Boul.
Goodman, Charles H.....Wall Bldg.
Gratz, Benjamin.....Rialto Bldg.
Graves, William W.....Metropolitan Bldg.
Greene, F. C., Jr.[1].....Rolla, Mo.
Greenman, Jesse M.....Missouri Botanical Garden.
Grindon, Joseph.....3894 Washington Ave.
Gundelach, William J.....4458 Washington Boul.
Gundlach, John H.....3615 North Broadway.
Guy, William E.....10 Portland Pl.

Haarstick, Henry C.....St. Louis Union Trust Bldg.
Hall, Robert A.[1].....323 Sixth Ave., S. E.,
Minneapolis, Minn.
Hambach, Gustav[2].....2605 Louisiana Ave.
Hard, M. E.[1].....Kirkwood, Mo.
Harder, Ulrich.....8015 Florissant Ave.
Hartmann, Rudolph.....3859 Flora Boul.
Hecker, Frederick[1].....Argyle Bldg.,
Kansas City, Mo.
Held, George A.....International Bank.
Hendrich, Walter F.....6228 Washington Boul.
Herf, Oscar .....Pierce Bldg.
Hoffman, Philip.....3657 Delmar Ave.
Hoke, William E.....304 North Third St.
Holman, C. L.....Laclede Gas Bldg.
Hughes, Charles Hamilton.....Metropolitan Bldg.
Hughes, Marc Ray.....Metropolitan Bldg.
Hume, H. Harold[1].....Glen St. Mary, Fla.
Hurter, Julius.....2346 South Tenth St.

Ilhardt, William K.....Euclid and Delmar Aves.
Irish, Henry C.....Commonwealth Trust Bldg.

James, George Oscar.....Washington University.
Johnson, Albert L.[1].....Mutual Life Insurance Bldg.,
Buffalo, N. Y.
Jonas, Ernest.....465 North Taylor Ave.

[1] Elected a life-member January 3, 1882.

Jones, Breckinridge.....45 Portland Pl.
Jones, Robert McKittrick.....6 Westmoreland Pl.

Kammerer, Alfred L.....Tower Grove and Flad Aves.
Kennett, Luther M.....3507 Lucas Ave.
Kessler, George E.....Security Bldg.
Kessler, J. J.....224 South Vandeventer Ave.
Keyes, Charles R.[1].....944 Fifth St., Des Moines, Ia.
King, Goodman.....78 Vandeventer Pl.
Kirchner, Walter C. G.....1127 North Grand Ave.
Klem, Mary J.....2853a Accomac St.
Knapp, H. P.....Eighteenth and Olive Sts.
Knight, H. F.....4433 Westminster Pl.
Knight, S. S.....6700 Manchester Ave.

La Brie, Joseph Damas[1].....504 Keith & Perry Bldg., Kansas City, Mo.
Lang, George, Jr.....3601 Salena St.
Langsdorf, Alexander S.....Washington University.
Larkin, E. H.....3600 North Broadway.
Lawver, Albert Briggs.....5715 Clemens Ave.
Leavitt, Sherman[1].....Illinois College, Jacksonville, Ill.
Lewis, E. G.[1].....University City, Mo.
Lichter, John J.....1740 Simpson Pl.
Loeb, Leo.....St. Louis Skin and Cancer Hospital.
Luedde, William H.....Metropolitan Bldg.
Lukens, C. DeWitt.....4908 Laclede Ave.

Mallinckrodt, Edward, Jr.....Mallinckrodt Chemical Works.
Mardorf, W. C.....2136 South Grand Ave.
Markham, George Dickson.....4961 Berlin Ave.
Mason, Silas C.[1].....R. F. D. No. 1, Bethesda, Md.
Matthews, Leonard.....5447 Cabanne Pl.
Mauran, John Lawrence.....1620 Chemical Bldg.
McBride, W. J.[1].....Haskell & Barker Car Co., Michigan City, Ind.
McCulloch, Richard.....3869 Park Av.
McLeod, N. W.....Lumberman's Bldg.
McMaster, LeRoy.....Washington University.
Meier, Theodore G.....5220 Washington Boul.
Mepham, G. S.....4434 Westminster Pl.

Mesker, Frank.....421 South Sixth St.
Mitchell, E. T.[1].....7730 Jeanette St., New Orleans, La.
Monell, Joseph T.....3454 Halliday Ave.
Monfort, W. F.....77 East May St.
Montague, John E.....National Bank of Commerce Bldg.
Moore, George T.....Missouri Botanical Garden.
Moore, Philip N.....Merchants' Laclede Bldg.
Moore, Robert.....61 Vandeventer Pl.
Mudd, Harvey G.....408 Humboldt Bldg.
Mueller, Ambrose[1].....Webster Groves, Mo.

Nagel, Charles.....Security Bldg.
Nasse, August.....2323 Lafayette Ave.
Nauer, Albert R.....4634 Nebraska Ave.
Nicolaus, Henry.....2149 South Grand Ave.
Nipher, Francis E.....Washington University.
Nisbet, Fritz.....New National Bank of Commerce Bldg.
Noel, Alexander H.....1323 Geyer Ave.
Nolker, William H.....Fifteenth and Pine Sts.
Norvell, Saunders.....LaSalle Bldg.

Ohlweiler, W. W.....4026a Shenandoah Ave.
Olshausen, Ernest P.....1115 Rutger St.
Opie, Eugene L.....Washington University, Medical Department.
O'Reilly, Andrew J.....1720 Pierce Bldg.
O'Reilly, Robert J.....27 Washington Terrace.

Padberg, Aloys J.....3900a Easton Ave.
Palmer, Ernest Jesse[1].....321 S. Allen St., Webb City, Mo.
Pammel, Louis Hermann[1].....Ames, Iowa.
Pantaleoni, Guido.....15 Lennox Pl.
Parker, George Ward.....501 Liggett Bldg.
Parker, L. S.[1].....Jefferson City, Mo.
Perkins, Albert T.....401 North Fourth St.
Pettus, Charles P.....33 Westmoreland Pl.
Pettus, W. H. H.....4373 Westminster Pl.
Pitzman, Julius.....6 Kingsbury Pl.

Post, Martin Hayward.....5371 Waterman Ave.
Priest, Henry Samuel.....New National Bank of Commerce Bldg.
Pyle, Lindley[1].....1619 Massachusetts Ave., Cambridge, Mass.

Randolph, Tom.....7 Kingsbury Pl.
Rassieur, Leo.....Fourth and Market Sts.
Rau, Philip.....4932 Botanical Ave.
Reber, H. Linton.....Kinloch Bldg.
Reber, Maxime.....La Salle Bldg.
Reed, George M.[1].....809 Virginia Ave., Columbia, Mo.
Robarts, Heber[1].....Belleville, Ill.
Roever, William Henry.....Washington University.
Rolfs, Peter H.[1].....Gainesville, Fla.
Rosenwald, Lucian[1].....412 Delaware St., Kansas City, Mo.
Rowse, E. C.....Chemical Bldg.
Ruf, Frank A.....5863 Cabanne Pl.
Rusch, Henri.....City Hall.

Sampson, Francis A.[1].....Columbia, Mo.
Sargent, Charles Sprague[1].....Jamaica Plains, Mass.
Sauer, William E.....Humboldt Bldg.
Scanlan, Philip C.....4450 Lindell Boul.
Schlueter, Robert E.....909 Park Ave.
Schlueter, W. H.[1].....Kirkwood, Mo.
Schramm, Jacob.....Missouri Botanical Garden.
Von Schrenk, Hermann.....Tower Grove and Flad Aves.
Schwarz, Ernest.....6310 Newstead Ave.
Schwarz, Frank.....1813 Lafayette Ave.
Schwarz, Henry.....440 North Newstead Ave.
Schwarz, Herman[1].....720 Clark Ave., Webster Groves, Mo.
Schweyer, George.....4252 Blaine Ave.
See, Thomas Jefferson Jackson[1].Naval Observatory, Mare Island, Cal.
Selby, Augustine Dawson[1].....Wooster, Ohio.
Senter, Charles Parsons.....1 Beverly Pl.
Shackleford, Ben G.....4511 McPherson Ave.

Shaffer, Philip A.....Washington University, Medical Department
Shahan, William E.....5234a Von Versen Ave.
Shannon, James I.....St. Louis University.
Shapleigh, Alfred Lee.....3636 Delmar Ave.
Shapleigh, John B.....Humboldt Bldg.
Sheldon, F. E.....Chemical Bldg.
Shepley, John F.....53 Portland Pl.
Shimek, B.[1].....Iowa City, Iowa.
Simmons, E. C.....Ninth and Spruce Sts.
Simmons, Wallace D.....Ninth and Spruce Sts.
Skinker, Thomas K.....Pierce Bldg.
Slater, Charles H.[1].....130 West Swan Ave., Webster Groves, Mo.
Sluder, Greenfield.....3542 Washington Ave.
Smith, D. S. H.....4388 Westminster Pl.
Smith, George M.....Washington University, Medical Department.
Smith, Jared G.[1].....Kealakekua, Hawaiian Islands.
Standley, Paul C.[1].....Division of Plants, National Museum, Washington, D. C.
Starr, John E.[1].....50 Church St., New York City.
Stelzleni, G. M.....1215 North Grand Ave.
Stennett, W. H.[1].....203 Linden Ave., Oak Park, Ill.
Stevens, Charles D.....5352 Vernon Ave.
Stevens, Wyandotte James.....4458 Olive St.
Stix, Charles A.....Stix, Baer & Fuller Dry Goods Company.
Stocker, George J.....2833 South Kingshighway Bl.
Sultan, Fred W.....112 North Second St.
Summa, Hugo.....Metropolitan Bldg.
Suppan, Leo.....2648 Russell Ave.

Taussig, Albert E.....Metropolitan Bldg.
Terry, Robert James.....Washington University, Medical Department.
Thacher, Arthur.....5185 Lindell Boul.
Thomas, John R.....4128 Washington Boul.
Thomasson, Hugh W.....703 North Grand Ave.
Thompson, Charles Henry.....Missouri Botanical Garden.
Timmerman, Arthur H.....6400 Plymouth Ave.
Todd, Charles A.....3723 Delmar Ave.

Tuholske, Herman.....465 North Taylor Ave.
Turner, Charles H.....Sumner High School.
Tuttle, Daniel S.....74 Vandeventer Pl.

Van Ornum, John Lane.....Washington University.
Vickroy, Wilhelm Rees.....2901 Rauschenbach Ave.

Walbridge, C. P.....Fourth and Market Sts.
Waldo, C. A.....Washington University.
Walsh, Julius S.....Fourth and Pine Sts.
Watts, Millard F.....5740 Cabanne Pl.
Weichsel, Hans.....6400 Plymouth Ave.
Werner, Louis.....Fullerton Bldg.
Wheeler, H. A.....3437 Lucas Ave.
Whelpley, Henry Milton.....2342 Albion Pl.
Whitaker, Edwards.....300 North Fourth St.
Whitelaw, Oscar L.....409 North Second St.
Whitten, John Charles[1].....Columbia, Mo.
Widmann, Otto.....5105 Von Versen Ave.
Wiedemann, H. E.....1105 Holland Bldg.
Wiener, Meyer.....3854 Westminster Pl.
Wiggins, Charles.....23 Portland Pl.
Wilson, M. E.....Washington University.
Winkelmeyer, Christopher.....4585 West Pine St.
Wislizenus, Frederick A.....Washington University.
Wolfner, Henry L.....4563 Forest Park Boul.
Woodward, Calvin Milton.....3013 Hawthorne Boul.
Woodward, Walter B.....Woodward & Tiernan Ptg. Co.
Wright, George M.....4457 Westminster Pl.
Wulfing, J. Max.....3448 Longfellow Boul.

Zahorsky, John.....1460 South Grand Ave.
Zellweger, John.....1900 Adelaide Ave.

CONSTITUTION.

ARTICLE I. NAME.

SECTION 1. This Association shall be called "The ACADEMY OF SCIENCE OF ST. LOUIS."

ARTICLE II. OBJECT.

SECTION 1. It shall have for its object the promotion of science.

SEC. 2. As means to this end the Academy shall hold meetings for the consideration and discussion of scientific subjects; shall take measures to procure original papers upon such subjects; and shall, as often as may be practicable, publish its transactions. It shall also establish and maintain a cabinet of objects illustrative of the several departments of science, and a library of works relating to the same. It shall also place itself in communication with other scientific institutions.

ARTICLE III. MEMBERS.

SECTION 1. The Academy shall consist of *Active Members, Corresponding Members, Honorary Members* and *Patrons.*

SEC. 2. *Active Members* shall be persons interested in science, and they alone shall conduct the affairs of the Academy.

SEC. 3. Persons not living in the City or County of St. Louis who may be disposed to further the object of the Academy by original researches, contributions of specimens, or otherwise, may be elected *Corresponding Members.*

SEC. 4. Persons not living in the City or County of St. Louis may be elected *Honorary Members* by virtue of their attainments in science.

Sec. 5. Any person conveying to the Academy the sum of one thousand dollars ($1,000) or its equivalent, may be elected a *Patron.*

Sec. 6. Persons may be admitted to any of the preceding classes of membership or dismissed therefrom in accordance with the regulations prescribed by the By-Laws.

ARTICLE IV. OFFICERS.

Section 1. The officers of the Academy shall be chosen from the active members, and they shall consist of a

President,
First Vice-President,
Second Vice-President,
Recording Secretary,
Corresponding Secretary,
Treasurer,
Librarian,
Three Curators,
Two Directors.

Said officers shall be elected at the time and in the manner prescribed by the By-Laws, and shall hold their offices for one year, or until their successors are elected.

Sec. 2. The duties of these officers shall be such as are customary and as prescribed by the By-Laws.

ARTICLE V. COUNCIL.

Section 1. The officers shall constitute the Council of the Academy and at its meetings five shall constitute a quorum.

Sec. 2. The duties of the Council shall be to consider all plans conducive to the welfare of the Academy; to audit all bills and order payment of such as they may approve; to consider all applications for membership; and to administer the business of the Academy, subject to the Constitution and By-Laws and to such instructions as may be given by the Academy.

ARTICLE VI. MEETINGS.

Section 1. The meetings of the Academy shall be held at such times and places as the By-Laws may direct.

ARTICLE VII. AMENDMENTS.

SECTION 1. Amendments to this Constitution shall be submitted in writing at a regular meeting. They shall be open to discussion until at least the second meeting thereafter. They may then be adopted by a two-thirds vote of a letter-ballot, conducted in the manner prescribed by the Council.

ARTICLE VIII. SECTIONS.

SECTION 1. To encourage and promote special investigations in any branch of science, members of the Academy may form Sections, which shall be constituted as herein provided.

SEC. 2. For the formation of a Section, written application shall be made to the Academy, at a regular meeting, by not less than six active members.

On the approval of this application by the affirmative vote of two-thirds of the members present at the next regular meeting, the Section shall be established and the names of the petitioners shall be recorded on its minutes as its founders.

SEC. 3. Sections may increase the number of their members by election, but only members of the Academy shall be elected members of any of the Sections.

SEC. 4. The officers of each Section shall be a Chairman and a Secretary, who shall be elected by its members at the first meeting of the Section, and subsequently at the first meeting in January of each year.

SEC. 5. The collections and books of each Section are the common property of the Academy. Donations of books and specimens made to or for any Section shall be received as donations to the Academy for the use of the Section.

SEC. 6. A report of the proceedings of each Section shall be submitted to the Academy at least once every month. Papers read before any Section with a view to publication by the Academy shall take the same course as papers read before the Academy.

SEC. 7. On all points not herein provided for, each Section shall be governed by the Constitution, By-Laws and instructions of the Academy.

BY-LAWS.

I. REGULAR MEETINGS.

The regular meetings of the Academy shall be held on the first and third Monday evenings of every month, unless otherwise ordered by the Council.

II. SPECIAL MEETINGS.

Special meetings may be called by the President at his discretion, and shall be called by him on the written request of three or more members.

III. NOTICE OF MEETINGS.

The Recording Secretary shall send a notice of each meeting to every active member at least two days before such meeting.

IV. QUORUM.

Seven members shall constitute a quorum, but four members shall constitute a legal meeting for reading of papers.

V. ORDER OF BUSINESS.

The order of proceeding, at the regular meetings of the Academy, shall be as follows:

1. Call to order by President.
2. Scientific Program.
    a. Papers as announced.
    b. Reports of Sections.
    c. Other communications (brief).
    d. Donations to the Museum and Library.
    e. Announcements by President (of special interest to visitors.)

3. Business Meeting.
   a. Minutes of last meeting.
   b. Report of the Council.
   c. Reports of Committees.
   d. Report of the Corresponding Secretary.
   e. Deferred Business.
   f. New Business.
   g. Elections.
   h. Proposals for Membership.
   i. Adjournment.

VI. CORRESPONDING SECRETARY.

It shall be the duty of the Corresponding Secretary to conduct the correspondence and report to the Academy.

VII. TREASURER.

The Treasurer shall collect all moneys due the Academy; be custodian of all its funds, and pay such bills against the Academy as the Council shall approve. The Treasurer shall deposit the moneys and invest the funds of the Academy in its name and by and with the advice of the Council. Besides his annual report to the Academy, the Treasurer shall make such further reports and statements concerning the financial affairs of the Academy as the Council may from time to time require. Before entering upon his duties, the Treasurer shall give bond in such sum as may be required by the Council.

VIII. LIBRARIAN.

The Librarian shall take charge of all books belonging to or deposited with the Academy, and shall be responsible for the same; he shall keep a catalogue thereof, in which the names of contributors shall be inscribed; he shall superintend the distribution of all the publications of the Academy.

IX. COUNCIL.

The Council shall act as a publication committee; shall prepare a program for each meeting, and make rules and regulations for their own guidance, not inconsistent with the Constitution and By-Laws.

X. ELECTION OF OFFICERS.

A nominating committee of three active members who are not officers of the Academy shall be elected at the first regular meeting in December. This committee shall nominate candidates for all the offices for the ensuing year, and report the nominations at the following meeting, when other nominations may be made by any active member. The Recording Secretary shall mail to every active member a list of the nominees for office, at least ten days preceding the annual meeting. The polls shall be closed at 6 p. m. on the day of the annual meeting, after which the nominating committee shall count the ballots and announce the results to the Academy. A plurality of the votes cast shall suffice to elect.

XI. VACANCIES.

All vacancies shall be filled by the Council in a regular or called meeting, notice whereof having been given at least two days previously.

XII. ELECTION OF MEMBERS.

A candidate for admission to the Academy shall be proposed by not less than two members at any regular meeting. The proposal must then be referred to the Council, and if upon examination they shall find the candidate to be eligible and worthy of membership, they shall order the question as to his admission to be submitted to the Academy for ballot. If there be five votes in the negative, the candidate shall be rejected, and shall not be again voted upon for twelve months after such rejection. But if the number of negative votes be less than five, the candidate shall be elected, but shall not be considered a member until he shall have paid the annual dues for the current year. Any failure to pay the annual dues within thirty days after the candidate has been notified of his election, shall work a forfeiture of all rights under said election, if the Council shall so determine. No entry shall be made on the record of the rejection of any candidate.

XIII. RESIGNATION OF MEMBERS.

Any member whose dues have been fully paid may withdraw from the Academy by a written resignation. Non-payment of dues for one year or longer may be treated as equivalent to resignation; but before any member is dropped from the rolls for delinquency, he shall be entitled to not less than four weeks' notice.

XIV. EXPULSION OF MEMBERS.

Upon the written request of five members, that, for cause stated, any member be expelled, the Council shall consider the matter, and if they deem it best, shall advise the member that his resignation will be accepted. He shall, however, have the right to demand and shall be given a copy of the charges against him, and shall have a reasonable time to present a written defense. The Council may then pass finally upon the matter, and if resignation has not been tendered, or a satisfactory defense made, may by an affirmative vote of four of their number expel the member, in which case they shall notify him and the Academy of their action, and his name shall be at once dropped from the list of members.

XV. INITIATION FEES AND DUES.

Annual dues shall be paid at the beginning of each year. Resident active members shall pay annual dues of six dollars, and non-resident active members shall pay annual dues of three dollars. There shall be no initiation fee.

XVI. HONORARY MEMBERS AND PATRONS.

Honorary members and Patrons shall be recommended by the Council, and elected by the unanimous vote of the members present at any regular meeting.

XVII. PUBLICATIONS.

Patrons, honorary members, and all active members not in arrears shall be entitled to one copy of all the publications of the Academy issued subsequent to their

election. Authors of papers shall be entitled to twenty extra copies of their individual papers.

XVIII. SALE OF REAL ESTATE.

The property conveyed to The Academy of Science of St. Louis on the eighteenth day of March, 1903, by Edgar R. Hoadley and Lavinia L. Hoadley, as a gift from Mrs. Eliza McMillan and William N. McMillan, shall not be mortgaged or voluntarily encumbered by the Academy of Science; and the said property shall not be sold, except with the consent of two-thirds of the members of the Academy of Science, obtained by letter-ballot, in such manner as may be prescribed by the Council; and, when sold, the proceeds of the sale or so much thereof as may be necessary, shall be used to provide a suitable location and building for the use of The Academy of Science of St. Louis.

XIX. AUTHORITY.

On all points of order and procedure, not provided for in the Constitution and By-Laws, *Robert's Rules of Order* shall be the authority.

XX. AMENDMENTS.

These By-Laws may be amended by two-thirds vote of all the members present at any regular meeting, provided notice of the proposed amendment shall have been mailed to every member at least one week before the vote thereon is taken.

ABSTRACT OF HISTORY.

ORGANIZATION.

The Academy of Science of St. Louis was organized on the 10th of March, 1856, in the hall of the Board of Public Schools. Dr. George Engelmann was the first President.

CHARTER.

On the 17th of January following, a charter incorporating the Academy was signed and approved, and this was accepted by a vote of the Academy on the 9th of February, 1857.

OBJECTS.

The act of incorporation declares the object of the Academy to be the advancement of science and the establishment in St. Louis of a museum and library for the illustration and study of its various branches, and provides that the members shall acquire no individual property in the real estate, cabinets, library, or other of its effects, their interest being merely usufructuary.

The constitution as adopted at the organization meeting and amended at various times subsequently, provides for holding meetings for the consideration and discussion of scientific subjects; taking measures to procure original papers upon such subjects; the publication of transactions; the establishment and maintenance of a cabinet of objects illustrative of the several departments of science and a library of works relating to the same; and the establishment of relations with other scientific institutions. To encourage and promote special investigation in any branch of science, the formation of special sections under the charter is provided for.

MEMBERSHIP.

Members are classified as active members, corresponding members, honorary members and patrons. Active membership is limited to persons interested in science, though they need not of necessity be engaged in scientific work, and they alone conduct the affairs of the Academy, under its constitution. Persons not living in the city or county of St. Louis who are disposed to further the objects of the Academy, by original researches, contributions of specimens, or otherwise, are eligible as corresponding members. Persons not living in the city or county of St. Louis are eligible as honorary members by virtue of their attainments in science. Any person conveying to the Academy the sum of one thousand dollars or its equivalent becomes eligible as a patron.

Under the By-Laws, resident active members pay annual dues of six dollars. Non-resident active members pay annual dues of three dollars only. Patrons and honorary and corresponding members are exempt from the payment of dues. Each patron, honorary member, and active member not in arrears is entitled to one copy of each publication of the Academy issued after his election.

Since the organization of the Academy, 1,324 persons have been elected to active membership, of whom, on December 31, 1913, 304 were carried on the list. Six patrons, Mr. Edwin Harrison, Mrs. Eliza McMillan, Mr. William Northrop McMillan, Mr. Henry W. Eliot, Mr. William Keeney Bixby and Mr. Edward Mallinckrodt, have been elected. Elections to honorary membership number 14 (page vi), and 225 persons (Vol. X., p. xii) have been elected to corresponding membership.

OFFICERS AND MANAGEMENT.

The officers, who are chosen from the active members, consist of a President, two Vice-Presidents, Recording and Corresponding Secretaries, Treasurer, Librarian, three Curators and two Directors. The general business

management of the Academy is vested in a Council composed of the officers.

The office of President has been filled by the following well-known citizens of St. Louis, nearly all of whom have been eminent in some line of scientific work: George Engelmann, Benjamin F. Shumard, Adolphus Wislizenus, Hiram A. Prout, John B. Johnson, James B. Eads, William T. Harris, Charles V. Riley, Francis E. Nipher, Henry S. Pritchett, John Green, Melvin L. Gray, Edmund A. Engler, Robert Moore, Henry W. Eliot, Edwin Harrison, Adolf Alt, Calvin M. Woodward, and William Trelease.

MEETINGS.

The regular meetings of the Academy are held at its building, 3817 Olive Street, at 8:15 o'clock, on the first and third Monday evenings of each month, a recess being taken between the meeting on the first Monday in June and the meeting on the third Monday in October. These meetings, to which interested persons are always welcome, are devoted in part to the reading of technical papers designed for publication in the Academy's Transactions, and in part to the presentation of more popular abstracts of recent investigation or progress. From time to time public lectures, calculated to interest a larger audience, are provided for in some suitable hall.

The following dates for regular meetings for the year 1914 have been fixed by the Council:

Jan	Feb	Mar	April	May	June	Oct	Nov	Dec
5	2	2	6	4	1		2	7
19	16	16	20	18		19	16	21

LIBRARY.

After its organization, the Academy met in Pope's Medical College, where a creditable beginning had been made toward the formation of a museum and library, until May, 1869, when the building and museum were destroyed by fire, the library being saved. The library now contains about 18,500 books and 16,000 pamphlets, and is open during certain hours of the day for consultation by members and persons engaged in scientific work.

PUBLICATIONS AND EXCHANGES.

Twenty-two octavo volumes of Transactions have been published since the organization of the Academy, and widely distributed. Two quarto publications have also been issued: one from the Archaeological Section, being a contribution to the archaeology of Missouri, and the other a report of the observations made by the Washington University Eclipse Party of 1889. The Academy now stands in exchange relations with 420 institutions or organizations of aims similar to its own.

MUSEUM.

After the loss of its first museum, in 1869, the Academy lacked adequate room for the arrangement of a public museum, and, although small museum accessions were received and cared for, its main effort, of necessity, was concentrated on the holding of meetings, the formation of a library, the publication of worthy scientific matter, and the maintenance of relations with other scientific bodies.

The Museum is at present located on the first floor of the Academy Building and has in it a number of specimens illustrating the various branches of natural science, among which may be mentioned the Yandell Collection of fossils, a collection of some 600 exotic butterflies, a collection of Mound Builder pottery and skulls from near New Madrid, Mo., and a collection of 25 meteorites. Our material forms but a nucleus of a museum which the Academy hopes to establish—a museum which we trust will be of benefit to the public and to the educational institutions of the city.

RECORD.

FROM JANUARY 1 TO DECEMBER 31, 1913.

The following list of papers were presented at the meetings during this period:

January 15, 1913:

S. BENT RUSSELL.—Demonstration and Design of Apparatus to Simulate the Working of Nervous Discharges.
(Published in Journal of Animal Behavior, Vol. 3, No. 1, 1913.)

J. L. VAN ORNUM.—Experiments on the Pointing of Pressure Tubes, to Eliminate Velocity Effects, in Water Pipes.

F. E. NIPHER.—The Strength of a Steel Magnet Dependent upon its Electric Potential.

February 3, 1913:

MOSES CRAIG.—Plant Improvement by Selection.

C. H. TURNER.—An Apparent Reversal of the Light Responses of the Common Roach.

F. E. NIPHER.—The Strength of a Steel Magnet Dependent upon its Electric Potential.

February 17, 1913:

F. E. NIPHER.—Effect of Electrification of Air on its Magnetic Permeability.

LEROY MCMASTER.—The Preparation and Properties of Some Ammonium Salts of Organic Acids.
(Published in American Chemical Journal, Vol. XLIX, No. 4, 1913.)

LEO LOEB.—Some Biological Aspects of Tumor Investigation.

March 3, 1913:

F. E. NIPHER.—The Behavior of the Magnetic Needle on Windy and Calm Days.
(Published in Transactions, Academy of Science of St. Louis, Vol. XXII, No. 2, 1913.)

R. A. Hall.—Fixation of Atmospheric Nitrogen.

S. S. Knight.—Some Microscopic Observations upon the Segregation of Impurities in Carbon-Iron Alloys.

R. J. Terry.—The Development of the Cranium in Mammals. II.

March 17, 1913:

E. G. Payne.—Social Effects of Some Recent Child Labor Legislation in Missouri.

C. M. Gill.—A Possible Explanation of the 'Inferno' at Fern Lake near Estes Park, Colorado.

F. E. Nipher.—The Effect of Wind on the Magnetic Needle.

April 7, 1913:

G. O. James.—How Worlds are Formed.

Julius Hurter.—Cobras.

April 21, 1913:

B. M. Duggar.—The Significance of Color in Plants.

C. A. Todd.—Observations on the Migratory Flight of a Butterfly.

R. A. Hall.—Preparation of Neutral Tri-Ammonium Citrate.

May 5, 1913:

M. E. Wilson.—The Geology of the Meramec Highlands Region.

C. A. Todd.—Further Observations on the Migratory Flight of a Butterfly.

May 19, 1913:

Geo. T. Moore.—Speculations on the Origin of Life.

June 2, 1913:

Hermann von Schrenk.—Recent Epidemic Appearance of Termites in St. Louis Houses.

H. M. Whelpey.—The Shrunken Human Heads of Bolivia.

October 20, 1913:

F. E. Nipher.—Variations in the Earth's Magnetic Field.

(Published in Transactions, Academy of Science of St. Louis, Vol. XXII, No. 4, 1913.)

H. M. Whelpey.—Problems in American Archæology.

November 3, 1913:

J. L. Van Ornum.—Forests and Floods.

November 17, 1913:

F. E. Nipher.—Uniform Motion of a Load upon an Inclined Plane.

W. H. Chenery.—The Problem of Organization; a Criticism of Theodor Ostwald's *Der Energetische Imperativ.*

C. A. Waldo.—A New Application of Electricity to the Production of Musical Tones.

December 1, 1913:

J. M. Greenman.—The Coastal-Plain Flora of Mexico.

W. H. Roever.—The Curve of Light on the Dome of the New Roman Catholic Cathedral.

(Published in American Mathematical Monthly, Vol. XX, No. 10, Dec., 1913.)

December 15, 1913:

J. A. Warner.—The Process of Manufacturing Anti-Toxins.

Meeting of January 6, 1913.

The Academy of Science of St. Louis met in the Academy Building, 3817 Olive Street, at 8 p. m., January 6, 1913; President Engler in the chair; attendance 20.

The President delivered his address as President of the Academy for the year 1912.

The Treasurer's report for the year 1912 was submitted.[3]

The report of the Curators for 1912 was read.[4]

The report of the Librarian for 1912 was presented.[5]

[3] Transactions, Vol. XXI, page lii.

[4] Transactions, Vol. XXI, page lii.

[5] Transactions, Vol. XXI, page lii.

The Nominating Committee reported the results of the election of officers for 1913, as follows:

President	E. A. Engler
First Vice-President	F. E. Nipher
Second Vice-President	A. E. Ewing
Recording Secretary	J. A. Drushel
Corresponding Secretary	Geo. O. James
Treasurer	H. E. Wiedemann
Librarian	Wm. L. R. Gifford
Curators	Julius Hurter
	Hermann von Schrenk
	Philip Rau
Directors	Adolf Alt
	H. M. Whelpley

The death of Dr. Geo. C. Crandall and of Mr. Irwin Z. Smith, active members, and of Professor G. C. Broadhead, corresponding member, was reported.

January 20, 1913.

President Engler in the chair; attendance 24.

The following donations to the Museum were reported:

R. F. O'Neal..European Starling (*Sturnus vulgaris*).
..Louisiana Centennial Medal, 1812-1813.

Mr. S. Bent Russell read a paper on "Demonstration and Design of Apparatus to Simulate the Working of Nervous Discharges."

First Mr. Russell explained why it is that an animal provided with muscles and a nervous system grows wiser with experience. For example, if an animal makes a movement that is followed by pain it will learn to refrain from the movement. In the same way he explained why the horse learns to jump at the crack of the whip without waiting for the blow; why the animal learns to avoid certain obstacles by turning certain ways; why a movement that is followed by a form of satisfaction becomes habitual; why the movements of certain muscles, after the proper experience, habitually occur together.

The explanation showed that all these actions are due simply to the nervous discharge following the channel that is most open at the time. The more frequently the channel has been used and the more recently, the more open it will be. The point was then made that if the channel is provided with two sensory endings and conditions are such that the two endings are excited in succession from time to time, it will become much more open, and movements will be made accordingly.

Thus experience determines development and variable responses are accounted for.

The theory thus given was supplemented by a brief description with lantern slides and sketches of a practical device which operates on something the same principle. The apparatus described is a hydraulic regulating system. The important parts are: 1st, a transmitter or triple slide valve with a timing attachment; 2nd, a measuring or balancing device governing a hydraulic cylinder or motor; 3rd, a system of key rods connected so that each key rod controls one or more transmitters and on the other hand each transmitter is controlled by one or more key rods.

The speaker demonstrated that the apparatus will respond to signals as a nervous system does, i. e., the responses are determined by previous experience. In other words, the speaker showed a practical arrangement of valves, pipes, springs, ratchets, cranks, pistons, etc, that will respond to signals and make movements like the nerves and muscles in an animal of some intelligence. The mechanism can be trained, can acquire habits, will move forward or back at a given signal, according to experience, will make one, two or three responses to a given signal, according to experience.

Professor J. L. Van Ornum spoke on "Experiments on the Pointing of Pressure Tubes, to Eliminate Velocity Effects, in Water Pipes," with especial reference to the auxiliary tubes of Pitometers.

For a long time it was assumed and still seems to be supposed by many, judging from statements in books and periodicals, that the pointing of a pitot tube to give a zero velocity indication when placed in a fluid stream should be at an angle of ninety degrees from the direction of flow; but this is not true. To the members of this Academy the most familiar proof of the fact is contained in paper No. 3, of Vol. XVI, of its Transactions, in which Professor Nipher states that a pitot tube in a current of air shows a negative velocity head (when pointed at an angle of ninety degrees from the direction of the air current) greater in amount than the maximum positive velocity head when directly facing the current of air; and that the angle of pointing to show a zero velocity head in air is sixty degrees.

The thesis experiments of Messrs. Patton and Wallace in the Washington University hydraulic laboratory nearly three years ago and later ones by Mr. Hooper, as well as Dr. Schuster's experiments at Dresden published about two years ago, are definite indications that the same facts are true in currents of water.

Among the other considerations discussed in the above mentioned theses is one perhaps more important than that just mentioned. It is the fact that, unless the pitot tubes have the theoretically required perfectly thin edge, the angle is increased from the sixty degree angle to one of greater size. When a cone, with its base coinciding with the plane of the mouth of the pitot tube, is used, its angle is greater than

sixty degrees in proportion to the increase of diameter of the base; and it does not require a very great expanse of mouth area to give an angle of ninety degrees, the one first assumed.

This conclusion has a particular point of interest in the fact that it indicates that the usual piezometer attachment to pipes for measuring pressure heads is correct, their normal direction having no connection with the sixty degree angle already discussed for the thin-edged pitot tubes.

Professor F. E. Nipher stated that he had obtained results in recent experiments which seem to indicate that the strength of a steel magnet depends upon its electric potential.

Mr. John E. Montague was elected to membership.

February 3, 1913.

President Engler in the chair; attendance 15.

The following donations to the Library were reported:

J. J. Kessler.....A pamphlet on The Nitrile of Fumaric Acid.
A. S. Langsdorf..Two volumes of Science.

Mr. Moses Craig read a paper on "Plant Improvement by Selection."

Mr. Craig briefly traced the history of plant breeding, outlining the Darwinian and De Vriesian views of the origin of new forms, with Mendel's law of character segregation. The importance of hybridization in hastening variation was mentioned with methods of inbreeding and methodical selection. He then gave many practical directions for improving our pomaceous, cereal and vegetable crops.

Dr. Chas. H. Turner read a paper on "An Apparent Reversal of the Light Responses of the Common Roach."

The paper discussed a series of experiments conducted with the common roach (*Periplaneta orientalis*) for the purpose of seeing if the negatively phototropic animal could be trained to refuse to enter a specific dark place; and, if that proved possible, to experimentally analyze the behavior. The electrical punishment method, devised by Professor Yerkes, in his study of the dancing mouse, was used.

According to the speaker this method has been used only once before in the study of insect behavior; that was by Mr. Szymanski[6] in studying the responses of several larval male cockroaches. A resumé of

[6] Journal of Animal Behavior, 2:81-90. 1912.

Mr. Szymanski's paper was given and the statement made that Mr. Szymanski did not experimentally determine whether the refusal to enter the dark chamber was the reversal of a negative phototropism or an example of learning, by means of associative memory, to avoid a disagreeable dark place.

A pen containing one dark chamber and one lighted chamber, or a pen containing one dark chamber and two lighted chambers, was placed on a platform composed of copper strips so arranged that an electric current could be sent through them at will. A marked roach was placed in a lighted chamber of one of the pens. If it was the roach's first time in the pen, it would immediately rush into the darkness. The current was then turned on, the shock of which would cause the roach to rush back into the light. Thereafter it would enter the dark chamber more cautiously. Each time it received a shock. After a while it could not be induced to enter the dark chamber. These experiments were conducted with roaches of both sexes and of several different ages.

The speaker said he believed the majority of the students of comparative psychology would call the above described behavior a reversal of a negative phototropism; but he insisted that it was just as logical to conclude that the roach, by means of associative memory, had learned to avoid a specific dark place because of certain disagreeable associations.

He further stated that he did not consider a learning curve a safe criterion for interpreting behavior, and based his statement upon the fact that Dr. Carr in experimenting with human beings in a maze obtained learning curves which, by the usual mode of interpretation, indicated a type of intelligence lower than that of the rat.

He also objected to adopting Professor Lloyd Morgan's method of selecting the simpler of two equally plausible solutions of an example of animal behavior. Dr. Turner insisted that, in such cases, the behavior should be experimentally analyzed; or else one should say frankly that the problem has not been solved.

In this case the behavior was analyzed by the following experiment: A roach which had thoroughly learned to refuse to enter the dark chamber of a pen resting upon the copper strips was transferred from that pen to a similar one resting on a different surface. In each case the roach would immediately rush into the dark chamber. The roach was then returned to the lighted portion of the pen resting on the copper strips. It then refused to enter the dark chamber. This was found to be true of numerous normal roaches of several different ages and of both sexes. Antennaeless roaches would enter the dark chamber under both conditions.

CONCLUSIONS.

1. By means of electric shocks roaches can be trained to avoid entering a specific dark place. This is not a reversal of a phototropism; but the result of learning to avoid a specific dark place because of certain disagreeable experiences associated with it.

2. Generally speaking, male roaches learn more quickly than female and young roaches are more apt than adults; but there are marked individual exceptions to this.

3. In the ability to learn and to retain what they have acquired roaches exhibit marked individuality.

4. Roaches that have acquired the habit of refusing to enter a dark place do not lose the habit when they moult.

5. Roaches that have learned to respond in the manner described continue to respond in that way even when several days elapse between experiments.

6. During sickness and just prior to death the retentiveness of the roach is much impaired.

Professor F. E. Nipher stated that he had recently obtained results which confirm his previous conclusion, that the strength of a steel magnet depends upon its electric potential. He has found this to be the case even when the magnet composed of a layer of fine steel wire is wholly enclosed in a covering of tin-foil.

February 17, 1913.

President Engler in the chair; attendance 36.

The following donations to the Library were reported:

D. L. Harris..Five pamphlets on the subject of rabies.
A. S. Pearse..Four pamphlets on crabs.

Professor F. E. Nipher addressed the Academy on "Effect of Electrification of Air on its Magnetic Permeability."

Professor Nipher stated that he had recently found that when a steel magnet is insulated and connected to either terminal of an influence machine, the other terminal being grounded, all points in the field of the magnet show an increase in magnetic intensity. There is an apparent increase in the magnetic moment of the magnet. This is really due to an increase in the permeability of the surrounding air.

The magnet thus acted upon was one of two deflecting magnets, placed on opposite sides of a magnetic needle suspended from a silk fiber, within a metal cylinder. The motion of the needle was observed by means of a telescope and scale, through a small opening in the metal shield, which was closed by a sheet of glass covered with wire gauze.

One of the deflecting magnets is put in contact with the influence machine. All disruptive effects are to be avoided. The needle shows a gradual deviation from the magnetic meridian, amounting to about four minutes of arc. This result is obtained even when the magnet is

wrapped in tin-foil, but not when it is within a large mass of cotton batting.

When the air around the charged magnet is disturbed by means of a palm-leaf fan, the deflection of the needle is not less than 15 seconds; its amplitude of vibration may be gradually increased, by operating the fan during alternate semi-vibrations. In this way the angle of vibration has been increased to about four degrees of arc. In a similar manner it can be quickly brought to rest.

This result seems to indicate that the electrified molecules of air behave somewhat like iron filings in the field of the magnet.

Arrangements are being made to place the deflecting magnets in adjoining rooms. The electrified magnet being placed between two large sheets of glass, may make it possible to obtain photographs of the lines of force.

The deviations of the needle here observed are of the same order of magnitude as those due to momentary variations in the magnetic field of the earth.

Professor LeRoy McMaster read a paper on "The Preparation and Properties of Some Ammonium Salts of Organic Acids."

Professor McMaster described a method of preparing the neutral ammonium salts of monobasic and dibasic organic acids, and gave an account of some of the properties of these salts. The method consists, briefly, in dissolving the organic acids in absolute alcohol or ether and passing dry ammonia gas into the solution. By this method were easily prepared the neutral ammonium salts of succinic, tartaric, ortho and meta-phthalic acids, propionic, iso-butyric and benzoic acids. The neutral salts of malonic, malic and cinnamic acids were prepared with some difficulty. Analyses of the prepared salts were given and proved the compounds to be neutral.

Dr. Leo Loeb presented a communication entitled "Some Biological Aspects of Tumor Investigation."

Weismann stated that Protozoa and germ cells of metazoa are potentially immortal while the somatic cells of metazoa are mortal. As far as the Protozoa are concerned his statement was controverted by Maupas, R. Hartwig, Calkins and others. The recent experiments of Henriquez and especially of Woodruff make it, however, very probable that his conclusion was essentially correct. As far as the somatic cells of metazoa are concerned, Weismann's conclusion was not warranted by facts, the evidence pointing merely to the conclusion that somatic cells can usually not reproduce the whole organism. The writer first pointed out in 1901 that facts established through experimental tumor investigation made it very probable that tumor cells are potentially immortal—as much as Protozoa and as germ cells. And a few years later he concluded further that, inasmuch as tumor cells are merely ordinary

somatic cells living under special conditions, the proof has been supplied—as much as that can be done—that ordinary somatic cells are potentially immortal. He also pointed out that this conclusion could still further be confirmed by serial transplantations of ordinary tissues in animals of various ages. He began such experiments a number of years ago and is continuing this work now under more favorable conditions.

Experimental tumor investigation has furthermore demonstrated that many somatic cells have a potential power to proliferate, which appeared almost unthinkable until recent years. One single epithelial or connective tissue cell being potentially able to produce masses of cells which surpass many times the number of cells composing a whole animal of the same species.

Germ cells show definite rhythms. Certain Protozoa also possess definite rhythms, as shown by Maupas, R. Hertwig, Calkins and others. Bashford and Calkins maintained that tumors also possessed definite rhythmic changes. Investigations carried out by M. S. Fleisher in our laboratory show such rhythms do not exist in the case of tumors. If they exist in the case of other somatic tissues, they are not primary attributes of these tissues, but due to secondary mechanisms.

The death of Mr. Gilbert G. Morrison was announced.

March 3, 1913.

President Engler in the chair; attendance 43.

The following donations to the Library were reported:

LeRoy McMaster..Two pamphlets on the preparation of ammonium salts of organic acids.

Professor F. E. Nipher gave some further observations on the behavior of the magnetic needle on windy and calm days.

Dr. R. A. Hall spoke on the "Fixation of Atmosperic Nitrogen."

Dr. R. J. Terry gave some of the results of his study of "The Development of the Cranium in Mammals. II."

Dr. Terry stated that Weiss's study of the occipital region of embryos of white rats revealed the fact that the dens epistrophei in these animals is composed of two elements, the one generally recognized as comparable with a centrum for the atlas, the other lying cephalad of this and forming the extremity of the dens. The latter is derived by independent chondrification in the tissue about the notochord cephalad of the atlas and where the former crosses the dorsal surface of the basal plate of the cranium. Weiss regarded this cephalic element as representing the centrum of an occipital vertebra or a proatlas.

The presence of an element in the dens epistrophei of cat embryos has been observed developing cephalad of the component identified as the centrum of the atlas and extending upon the basal plate of the cranium. This component is derived from the mesenchyma which, in the form of a cone traversed by the notochord, extends from the level of the atlas cephalad upon the basal plate and there lies in a deep median groove. Chondrification in this part of the dens occurs later than in that part related to the atlas, but the two processes appear not to be entirely distinct.

Mr. S. S. Knight presented a paper entitled "Some Microscopic Observations upon the Segregation of Impurities in Carbon-Iron Alloys."

This paper was accompanied by some seventy-five slides, showing original work done in the field of metallography, and detailed largely the isolation and description of the impurities found in the form of phosphides, sulphides, silicides and cuprides as they occur in cast material, which has had no work done upon it.

March 17, 1913.

President Engler in the chair; attendance 31.

Dr. E. G. Payne addressed the Academy on "Social Effects of Some Recent Child Labor Legislation in Missouri."

The law considered was section 1716, Revised Statutes of Missouri, limiting the labor of children between the ages of fourteen and sixteen years to eight hours per day. The effect of the law is to exclude laborers under sixteen from factory employment, because of the inability of managers to use with profit laborers working on two schedules. An examination of available data relating to school attendance showed that laborers excluded are not in school. Also that the law has not tended to deter children affected by the law from leaving school when they become fourteen. The children between fourteen and sixteen are, therefore, in "blind alley" vocations; i. e., working as newsboys, errand boys, office boys, street vendors, drivers, delivery boys, etc., and upon the streets, unemployed. In so far as the work of the children is necessary for the family support the result has been bad, as there has resulted keen competition for the positions that are now open to children who are compelled to work, but are excluded from factory employment. A study of data gathered by the Bureau of Labor, the Chicago School of Civics and Philanthropy, and the records of the Juvenile Court in St. Louis showed that tendency to crime among children is most marked among those engaged in the "blind alley" vocations and among the unemployed. These data led to the conclusion that the law has resulted in serious evil consequences and that supplementary legislation is necessary to make the law effective.

Mr. Charles M. Gill presented "A Possible Explanation of the 'Inferno' at Fern Lake near Estes Park, Colorado."

The "Inferno" lies on the shore of Fern Lake, fourteen miles southeast of Estes Park, Colorado, and at the head of the canyon of the Big Thompson River.

The feature in question consists of a mass of rock fragments, four hundred feet in length and sixty in breadth, arranged so as to form an elongated oval depression. The rim consists of granite masses from four to twelve feet in diameter. The size of the boulders grades down to a diameter of about a foot at the bottom of the pit twenty feet below.

The topography of the entire region is glacial. The basin of Fern Lake is glacially scooped, and a moraine has raised the basin rim on the northeast side.

The hypothesis consists of three parts:—

1st. That the source of the material is the cliffs above the formation. This is borne out by the identity of the granites and the scarred cliff.

2nd. That the fall of material was probably due to earthquake. In the canyon below and in the foot of the cliffs in this region are other rock masses of about the same degree of weathering.

3rd. That the peculiar arrangement of the rocks results from the fall of the mass upon a shallow glacier then filling the lake basin. When the ice melted near the cliff base, other masses were released. Upon the complete melting the larger fragments are found at the outer edge as is usual in glacial kettle holes.

The degree of weathering is comparable with that of glaciated surfaces of the same granite in this region.

The absence of even a trace of vulcanism precludes it as a cause.

Professor F. E. Nipher made some remarks on the effect of wind on the magnetic needle.

April 7, 1913.

President Engler in the chair; attendance 69.

The following donations to the Museum and Library were announced:

H. M. Whelpley . . Section of a fossil tree trunk from the Petrified Forest, Arizona.

Otto Widmann. . . . A pamphlet on the birds of Estes Park.

Dr. G. O. James gave an illustrated lecture on "How Worlds are Formed."

Dr. James discussed:

1st. Laplace's theory of the formation of the Solar System.

2nd. See's capture theory of the Planetary Systems.

3rd. The heavenly bodies, especially the earth, as the home of living beings.

4th. Radiation and constitution of the sun.

5th. Dying of the sun. Origin of nebulae.

6th. Distribution of life through the universe.

Mr. Julius Hurter read a paper on "Cobras."

April 21, 1913.

President Engler in the chair; attendance 35.

The following donation to the Library was reported:

LeRoy McMaster..A pamphlet on the preparation and properties of the ammonium salts of some organic acids.

Dr. B. M. Duggar addressed the Academy on "The Significance of Color in Plants."

Dr. C. A. Todd read a paper on "Observations on the Migratory Flight of a Butterfly."

Anosia plexippus (Monarch) is believed not to hibernate in the colder parts of the United States, and, consequently, must migrate to escape frost. It migrates with the birds and much in the same fashion. *A. plexippus* is supposed to winter in the Gulf States. Butterflies, according to reasonable interpretation of their lives, are largely, if not altogether, automatic. The autumn migration of *A. plexippus* over great distances, always maintaining a fixed direction; when temporarily diverted or checked, with mechanical promptitude resuming that direction (most remarkably so in a flight specially described in the paper), all this would lead logically to assume the operation of a force wholly external, a force that compels the insect to continue in a fixed direction of line of flight, just as the magnetic needle, after having been disturbed from a state of rest, must resume its appointed place. The present trend of science aiming to obliterate the chasm hitherto supposed necessarily to exist between the natures of animate and inanimate things, would justify such comparison. In other words, we seem justified in assuming that the migratory flight of *A. plexippus* is purely automatic, and possibly due to "magnetic" influence.

As this flight closely resembles that of birds, if it be not identical in the main features, the same theory is applicable to both.

Owing to the lack of universal and systematic observation of the flight, its full course and extent has not been mapped out. Such observations will require united action on the part of all scientific bodies. Action in that direction should be initiated at Washington and might need to be extended over several years according to results.

Professor Robert A. Hall reported that he had succeeded in preparing Neutral Tri-Ammonium Citrate.

Neutral Tri-Ammonium Citrate was prepared by passing an excess of dry ammonia gas into a well cooled solution of the water free citric acid in an anhydrous solvent.[1] The yield is quantitative. Tri-ammonium citrate thus prepared is a stable, white, crystalline substance, not hygroscopic and not affected by the CO_2 of the atmosphere. It dissolves readily in water and the freshly prepared solution is neutral to sensitive litmus, azo-litmin, corallin, methyl red, etc. Rigorous analyses of both the ammonia and the citrate content of the salt show it to be the tri-ammonium citrate. Further investigation of its physical-chemical properties are being made.

As the method of preparation is simple and inexpensive and the yield good it is evident that this means a solution of the difficult problem of the fertilizer chemist in the preparation of neutral ammonium citrate solution for the determination of the citrate insoluble phosphoric acid in fertilizer analysis.

May 5, 1913.

President Engler in the chair; attendance 29.

The following donations to the Museum and Library were reported:

Edward Evers..One volume of Naturwissenschaftliche Rundschau and two volumes of Globus. Fourteen pieces of Zuni pottery.

Professor M. E. Wilson gave an illustrated lecture on "The Geology of the Meramec Highlands Region."

Dr. Chas. A. Todd, who read a paper at the preceding meeting on "Observations on the Migratory Flight of a Butterfly," exhibited fresh specimens of returning Monarchs (*Anosia plexippus*) badly battered, and bleached in color, showing evidence of travel and long exposure to weather.

May 19, 1913.

President Engler in the chair; attendance 51.

Dr. Geo. T. Moore addressed the Academy on "Speculations on the Origin of Life."

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[1] This body was first prepared by this method two years ago at the time of the investigation of the Conductivity Method of Preparing Neutral Ammonium Citrate Solutions but a press of other research prevented its analysis and complete identification until the present time.

June 2, 1913.

President Engler in the chair; attendance 37.

The following donation to the Library was announced:

Julius Hurter..Proceedings of the Seventh International Zoological Congress.

Dr. Hermann von Schrenk spoke on "Recent Epidemic Appearance of Termites in St. Louis Houses."

Dr. H. M. Whelpey gave an illustrated account of "The Shrunken Human Heads of Bolivia."

Messrs. C. S. Mepham and J. Max Wulfing were elected to membership.

The death of Mr. Julian Bagby and Mr. Geo. W. Letterman was reported.

George Washington Letterman.

With the death of Mr. George W. Letterman in Allenton, Mo., on May 28, 1913, there passed one of the few persons who have worked upon the botany of St. Louis and vicinity during their whole life time. His herbarium represents the flora of St. Louis county probably better than any other in existence.

While Mr. Letterman had worked especially in Missouri, he was an authority on the plants of the region included in eastern and northern Texas, Louisiana, Arkansas and Oklahoma.

George W. Letterman was born in Pennsylvania seventy-two years ago. While at State College in Center County, the Civil War broke out and young Letterman enlisted as a private, serving until the end of the war, when he was mustered out of the service with the rank of captain of volunteers.

He crossed the plains to New Mexico in 1866, returned to Pennsylvania, and again going west to Kansas with the idea of farming in that state, he settled finally in 1869 in Allenton, Mo., a hamlet about thirty miles west of St. Louis.

Here Mr. Letterman taught school for many years also serving as superintendent of schools in St. Louis county.

Shortly after settling in Allenton, Mr. Letterman met August Fendler, the botanist, who had a farm in that neighborhood. This meeting stimulated his interest in plants, especially in trees. For Dr. Engelmann Letterman made large collections of plants in the neighborhood of Allenton, with many notes on the oaks and hickories.

In 1880 he was appointed special agent of the Census Department of the United States to collect information about the trees and forests of Missouri, Arkansas, western Louisiana and eastern Texas. Later he collected specimens from the same region for the Jesup Collection of

North American woods in the American Museum of Natural History in New York. The name *Lettermani* commemorates his numerous discoveries in these little known regions.

October 20, 1913.

President Engler in the chair; attendance 46.

The following donations to the Museum and Library were reported:

A. F. Onderdenk..Fifteen volumes of the Scientific American Supplement.

G. R. Agassiz.....Letters and Recollections of Alexander Agassiz with a sketch of his life and work.

Professor F. E. Nipher addressed the Academy on "Variations in the Earth's Magnetic Field."

Dr. H. M. Whelpley gave an illustrated lecture on "Problems in America Archæology."

The death of Mr. Adolphus Busch, of Mr. Moses Craig, of Mr. Chas. H. Huttig, of Mr. Elias Michael, and of Dr. William Taussig was announced.

November 3, 1913.

President Engler in the chair; attendance 26.

Professor J. L. Van Ornum addressed the Academy on "Forests and Floods."

Professor Van Ornum outlined the complexity of the relation between rainfall and runoff. He then indicated that, while exceptions occur and greater differences exist, the general tendency of forests is to somewhat equalize and increase the rainfall locally, to reduce evaporation from the soil, to prolong the melting of snow, to retard surface flow and to prevent the erosion of soil in hilly and mountainous country. Yet the essential question is whether this tendency is potent enough to be important. The impossibility was shown of deductively determining the quantitative value of the forest influence, with any approach to satisfactory results, by attempting the evaluation of the different factors contributing to that influence.

Then four investigations were reviewed, in three of which no appreciable effect of extensive change in forest cover could be detected in the runoff phenomena, and in one of them the effect was apparent.

The conclusion was reached that the forest influence is sometimes considerable on watersheds of small area, but that it is slight on those of moderate extent and generally is entirely imperceptible in its effect on flood flow in the main rivers of large drainage basins.

Messrs. A. F. Ewers, Benjamin G. Shackleford and Charles H. Slater were elected to membership.

NOVEMBER 17, 1913.

President Engler in the chair; attendance 18.

The following donations to the Museum and Library were reported:

C. H. Turner.....Six pamphlets on entomology.
H. L. Webb.....Biography and Unparalleled Discoveries of T. J. J. See.
H. M. Whelpley...A Flying Fox from the Philippine Islands.

Professor F. E. Nipher called attention to the well known equations for uniform motion of a load upon an inclined plane.

Some of the conditions which follow from the equations had never suggested themselves to him until recently, and inquiry had revealed the fact that they appeared new and interesting to his associates.

Let $R = mg$ be the weight of a block which is drawn uniformly up a plane making an angle α with the horizontal. Let f be the coefficient of friction. Let R' be the component of R down the plane, and R'' the component at right angles to the plane.

The force which will produce uniform motion up the plane is

$$P = R' + fR'' = R(\sin\alpha + f\cos\alpha) \qquad (1)$$

Assuming R constant and α variable the force P will be a maximum when

$$\frac{1}{R}\frac{dP}{d\alpha} = \cos\alpha - f\sin\alpha = 0.$$

or when

$$\cot\alpha = f$$

This angle is the complement of the angle which the plane would make with the horizontal if P were made zero, and the block slides uniformly down the plane.

For this condition of maximum P

$$\text{Sin}\,\alpha = \sqrt{\frac{1}{1+f^2}} \qquad \cos\alpha = \frac{f^2}{1+f^2}$$

$$P = R\sqrt{1+f^2}$$

When $f = 0.42$, which is the value for an oak block upon an oak plank, $P = 1.085\,R$. This force is therefore greater than that required to lift the load R by about 8%.

There are therefore two positions of the plane for which $P = R$, or for which

$$\text{Sin}\,\alpha + f\cos\alpha = 1$$

This equation when solved as a quadratic gives

$$\text{Sin}\,\alpha = \frac{1}{1+f^2} \pm \frac{f^2}{1+f^2}$$

$$= 1 \qquad \text{or } \frac{1-f^2}{1+f^2}$$

Hence

$$\text{Cos}\,\alpha = 0 \text{ or } \frac{2f}{1+f^2}$$

For $f = 0.42$

$$\alpha = 90° \text{ or } 44°\ 26'$$

If the force P is decreased to some value P_1 so that the block slides uniformly down the plane, then

$$P_1 = R' - fR'' = R(\text{Sin}\,\alpha - f\cos\alpha) \qquad (2)$$

This force P_1 is the force which horses must apply to a wagon in descending a hill, if they are to maintain uniform motion.

Equations (1) and (2) may be written

$$y = \sin\alpha \pm f\cos\alpha.$$

When the final term has the + sign, $y = P$, and for the — sign, $y = P_1$. The two curves which represent the values of y for direct and reversed motion on the plane, are symmetrical in y with respect to the sine-curve which represents both direct and reversed motion on the frictionless plane. As f becomes smaller the two curves approach the sine-curve.

The work done in raising the mass m through any height heing W_o, the work required to slide the mass up any plane having any angle of inclination through a vertical height h_o is

$$W = W_o\,(1 + f\cot\alpha)$$

This work increases as α decreases. It is W_o when $\alpha = 90°$, and it is $2\ W_o$ when $\tan\alpha = f$, or the angle of the plane is the angle of friction. As α diminishes to zero, the value of W increases to an infinite value.

Professor Winthrop H. Chenery addressed the Academy on "The Problem of Organization; a Criticism of Theodor Ostwald's *Der energetische Imperativ.*"

Professor C. A. Waldo described "A New Application of Electricity to the Production of Musical Tones."

Messrs. Jesse M. Greenman and Albert E. Taussig were elected to membership.

DECEMBER 1, 1913.

President Engler in the chair; attendance 30.

Dr. J. M. Greenman addressed the Academy on "The Coastal-Plain Flora of Mexico."

Professor Wm. H. Roever spoke on "The Curve of Light on the Dome of the New Roman Catholic Cathedral."

Dr. R. J. Terry, Mr. Otto Widman and Mr. Lewis M. Dougan were elected a committee to nominate officers for 1914.

In accordance with Article XX of the By-Laws the following changes in Articles XV and XVII were voted upon and unanimously adopted:

By-Law XV, entitled Initiation Fees and Dues, which read:

> "Resident active members shall pay an initiation fee of five dollars, and annual dues of six dollars, payable at the beginning of each year. Non-resident active members shall pay an initiation fee of five dollars and annual dues of one-half the dues for resident active members, payable at the beginning of each year."

to read as follows:

> "Annual dues shall be paid at the beginning of each year. Resident active members shall pay annual dues of six dollars, and non-resident active members shall pay annual dues of three dollars. There shall be no initiation fee."

By-Law XVII, entitled Publications, which read:

> "Patrons and all active members not in arrears shall be entitled to one copy of all the publications of the Academy issued subsequent to their election. Authors of papers shall be entitled to twenty extra copies of their individual papers."

to read as follows:

> "Patrons, honorary members, and all active members not in arrears shall be entitled to one copy of all the publications of the Academy issued subsequent to their election. Authors of papers shall be entitled to twenty extra copies of their individual papers."

Mr. W. F. Monfort was elected to membership.

December 15, 1913.

President Engler in the chair; attendance 34.

The following donations to the Museum were reported:

Julius Hurter..27 species of Missouri snakes.
8 species of Missouri lizards.
8 species of Missouri turtles.
10 species of Missouri toads and frogs.
15 species of Missouri salamanders.

Dr. J. A. Warner gave an illustrated lecture on "The Process of Manufacturing Anti-Toxins."

The following report of the Nominating Committee was read:

St. Louis, Mo., Dec. 15, 1913.

To The Members, Academy of Science,
St. Louis, Mo.

Gentlemen: Your committee, elected Monday, December 1st, to nominate officers for the year 1914, beg to submit the following report of nominations:

For President	Edmund A. Engler.
For First Vice-President	Francis E. Nipher.
For Second Vice-President	George T. Moore.
For Recording Secretary	Charles H. Danforth.
For Corresponding Secretary	George O. James.
For Treasurer	H. E. Wiedemann.
For Librarian	Arthur E. Bostwick.
For Curators	Julius Hurter.
	Philip Rau.
	Hermann von Schrenk.
For Directors	Adolf Alt.
	H. M. Whelpley.

Respectfully submitted,
(Signed)
O. Widmann,
L. M. Dougan,
R. J. Terry.

The death of Dr. John Green and of Mr. Thomas D. Witt was reported.

The President appointed Messrs. Hermann von Schrenk, Adolf Alt and Henry Schwarz a committee to draft resolutions on the death of Dr. John Green, past president of the Academy.

Mr. Roy M. Eilers was elected to membership.

REPORTS OF OFFICERS.

Treasurer's Report.

Receipts.

Balance from 1912	$ 348.07
Dues from members	1,570.75
Rent from tenant societies	605.00
Radiators sold	30.00
Academy's Transactions sold	18.70
Interest on balance	30.20
Income from endowment fund	805.56
Total receipts for the year	$3,408.28

Expenditures.

Salaries	$1,352.00
Water license	14.00
Gas, electric light and power	81.47
Fuel	177.73
Telephone	54.15
Printing	769.66
Current expenses	576.07
Remodeling Museum	300.21
Total expenditures for the year	3,325.29
Balance December 31, 1913	82.99
	$3,408.28

Respectfully submitted,

(Signed) H. E. Wiedemann,
Treasurer.

Librarian's Report

The Librarian reported that the accessions to the library for the year 1913 by exchange with 114 home and 306 foreign societies amounted to 671 volumes and 181 pamphlets, by donation 22 volumes and 24 pamphlets, and by purchase 2 volumes.

The Transactions for the year were sent to 114 home and 306 foreign societies.

Report of the Entomological Section.

During the year the section held eight meetings, with an average attendance of ten. The meetings were interesting and instructive, and

all of the papers presented were freely discussed. At most of the meetings specimens were exhibited.

The following papers were presented:

February 26.—An Apparent Reversal of the Light Responses of the Common Roach, by C. H. Turner.

March 16.—The Fertility of the Cecropia Eggs in Relation to the Mating Period, by Phil Rau.

April 30.—Behavior of Certain Wasps, by Phil Rau.
Love Dances of Certain Insects, by C. H. Turner.
Some Remarks on the Life of Miss Murtfeldt, by Hermann Schwarz.

May 29.—Orthogenesis in the Catocala Moths, Hermann and Ernst Schwarz.
A Method of Mounting Butterflies for School Use, by Hermann Schwarz.
Mr. Phil Rau reported that the bag-worm, by constricting the twig caused the death of that portion of the twig which lies beyond the constriction.

June 25.—Differentiation of the Four Families of Butterflies, by Hermann Schwarz.

October 28.—Field Experiments on the Auditory Powers of the Catocala Moths, by C. H. Turner and Ernst Schwarz.

November 25.—Sleeping Habits of Certain Wasps and Butterflies, by Phil Rau.
Review of Some Recent Articles in Insect Behavior, by C. H. Turner.

December 30.—Behavior of the Common Roach on the Maze; with a Brief Resume of the Use of the Maze in Comparative Psychology, by C. H. Turner.

In response to a letter received from Mr. Banks at the June meeting, Mr. J. T. Monell and Dr. C. H. Turner were appointed to serve on a National Committee of Nomenclature.

At the October meeting Mr. Hermann Schwarz reported that, on the 16th of October, 1913, he found on a clothes prop in his yard, a crysalis of *Anosia plexippus*. He was convinced that a Crysalis formed that late in the season would remain such throughout the winter; hence he considers this a hint that this butterfly hibernates in the pupal stage, instead of migrating southward and returning in the spring as is the common belief.

(Signed) PHIL RAU, Chairman,
C. H. TURNER, Secretary.

A DENTATE FLINT SPADE.

Found in Jefferson County, Missouri (one half natural size).
H. M. WHELPLEY Collection

DENTATE FLINT SPADES.

At the meeting of the Academy for June 4, 1906,[8] Dr. H. M. Whelpley exhibited a specimen of an Indian flint spade with the edge of the cutting end distinctly dentated by furrows extending back from one-half to one inch on both sides. (See Plate A.)

It is now generally believed that these furrows are the result of the mechanical action of the soil on the flint. Iron spades, hoes and plow shares are sometimes similarly dentated after long use. The dentated flint spades are always polished and show other evidences of much use.

Such spades are comparatively rare, but may occur wherever flint spades are found. Some are made of the light colored Mill Creek, Union County, Illinois, flint and others are from the brown "Tennessee flint."

[8] Transactions Vol. 16. p. CXX.

THE BIOLOGY OF STAGMOMANTIS CAROLINA.*

PHIL RAU AND NELLIE RAU.

INTRODUCTION.

In attempting to carry on experimental studies on the color and color changes of *Stagmomantis carolina,* we found it necessary to learn more than has hitherto been recorded concerning many of the simple facts of the insect's life history. The following pages embody the knowledge gleaned from three summers' observations on the biology of a good many hundreds of living insects, either free in the garden or in captivity under individual observation.

The insect was first mentioned by Linnaeus in 1763, and after parading under a goodly number of generic and specific names, is today known as *Stagmomantis carolina,* belonging to the order Orthoptera and the family Mantidae.[1]

DISTRIBUTION.

The family Mantidae is for the most part tropical. Only two species of this genus are at present known in the United States. Our species is found from Florida to Arizona, north to Maryland, Southern Illinois, Missouri, Kansas and Utah.[2] Henshaw (1900) reports it from Rhode Island, and Baker (1905) from California.[3] That the species seems to be gradually working its way northward is evidenced by Rathvon's Report (1862). He says that egg-cases brought from Maryland to Lancaster City, Pa., brought forth their broods and this introduced population persisted in this climate for two or three consecutive seasons, withstanding the temperature of

*Presented before The Academy of Science of St. Louis, May 20, 1912.

[1] Some of the common names are mule-killer, devil's-horse, rear-horse, camel-cricket, devil's-riding-horse, Carolina mantis, praying mantis. For scientific names, see bibliography.

[2] *Fide* Scudder.

[3] Also reported from Mexico, Central and South America. See bibliography.

—10° F. Even here in St. Louis the mantis population survives year after year, apparently unaffected by the occasional extremes of 15° to 20° below zero. Its frequent occurrence in this region was known to Riley in 1868, and during the years 1908-1911, old egg-cases were taken at Meramec Highlands, Mo., Crêve Coeur Lake, Mo., and Forest Park, St. Louis, Mo., while the greatest source of egg-case supply was the board fences in gardens in the southwestern part of this city. Nymphs were also found at Falling Springs, Ill.

Anatomy.

The internal or external anatomy of the insect has never been worked out to any considerable extent, but the following general notes may help to make clear the discussions which follow.

The head is attached to the prothorax by a flexible membrane, which makes it possible for the head to turn almost completely around (Plate I) and the animal when quietly at rest, awaiting its prey, stealthily moves its head in all directions, sometimes holding it in one difficult position for many minutes. The mouth parts are of course formed for biting. Besides the two compound eyes, the head contains three simple eyes. Just how these function or what is their distance of vision is not known, but that they are highly developed for the purpose of distinguishing good prey, on the wing or moving about, is obvious. The insect will eye its victim serenely, sometimes for many minutes, before making the final leap, or back away from distasteful food when offered it.

The prothorax is greatly modified and bears the highly developed pair of forelegs. These appendages are extremely useful to the animal for catching and holding its prey; without these in their highly developed spinal condition, the animal would have no means of offence or defence. Their power is really surprising; the sensation in placing one's finger between them is anything but

pleasant. The two pairs of hind legs are used for carrying the body, while these are held high in the air, ever ready to pounce upon some unheeding prey.

The front coxa is so much enlarged as frequently to be mistaken for the femur (Pl. XVIII, Fig. 1); the femur and tibia are fully supplied with spines, and the five-jointed tarsus is comparatively small. The double row of spines on both femur and tibia are immovable; in addition to these we find in the adults of both sexes three spines, which are movable, located in the middle of the femur and between the two rows, as indicated in Pl. XVIII, Fig. 1, point X. When the tibia is folded against the femur, the large, curved spine at the end of the former fits nicely into the groove of the latter just behind these three movable spines, while these bend nicely inward. This modification is of great advantage to the insect in holding prey. How some of the spines first became movable, and these situated just were they would be of most use, while the others remained inflexible, can be explained most readily, it seems to me, by Natural Selection. This insect has been described and re-described and has had at least eight different names, but nowhere in the literature is mention made of these three spines which are movable. Evidently the descriptions were made from dead material; this shows the distinct advantage of working with living animals.

This high modification of the forelegs is correlated with a similarly modified prothorax (see Pl. XVIII. Fig. 1). It will be seen that the forelegs are attached to this part. How this correlation came about remains a problem of interest. It must be that Natural Selection again, while modifying the appendages to be of use to the insect for long reaching and powerful grasping, harmoniously modified the part that carries them as well. It would certainly be impossible for such an enormous pair of legs to be appended to the usual Orthopteran thorax. On the other hand, what use would economical Nature find in enlarging a part which carries only simple legs, such as

the other members of the group have? In other Orthoptera such as the mole-cricket, we find the forelegs modified for digging; in the grasshopper, cricket and katydid, the hind legs are developed for jumping, and in the roaches all of the legs are specialized for running. In all of these insects the thorax which carries all three pairs of legs is comparatively small, just as is the meso- and metathorax in the mantis, but here the prothorax which carries these forelegs is greatly enlarged. Pl. XVIII, Fig. 1 shows clearly the comparative size of the parts.

To the meso- and metathorax are attached the two pairs of wings and the two hind pairs of legs. When nymphs are caught by the hind legs, they frequently walk away, leaving the limbs in one's hand. These undoubtedly regenerate, since individuals are not infrequently found with one appendage which is smaller than the others. In the younger nymphs, which are fast moving creatures, all six legs are used for locomotion. The adults are slow moving insects, especially so the females; they seldom use the forelegs for walking, but depend upon the hind legs alone for that purpose and keep the forelegs free for grasping prey.

The size and color of the wings differ in the sexes, as the illustrations show. The male can fly for a considerable distance, much in the manner of a locust's flight, but the adult female cannot fly, partly on account of her aborted wings and partly because of being heavily laden with eggs, although she spreads her wings to ease the fall when she drops to a lower surface. The males occasionally come to the lights, but I have yet to observe the first female there.

The function of the cerci is as yet little understood. Sharp (1895, p. 247) thinks that they assist the insect in emerging from the egg-case, and I shall later show how in the adult they may serve as sense-organs in the fashioning of the egg-case.

The Structure of the Egg-Case.

Before taking up the details of the emergence and the nymph forms, it will be well to get clear in mind the architecture of the nest from which they emerge.

The egg-case is built by the mother mantis in the fall and the old insect dies with the approach of winter. The new organism hibernates in the egg-stage, amply protected in the oötheca. The number of individuals normally contained in one of these cases varies from 36 to 140.

Photographs of 39 egg-cases (Pl. XV) will give an adequate idea of their general appearance and variation, while Pl. XVI shows the different sections and the details of architecture. We can best appreciate this picture if we imagine each egg-case to be a dwelling of many rooms (cells), grouped into two rows of suites of four rooms, each suite having a gallery which runs past the end of each room. This gallery has an opening at the top, through which the four occupants of the one suite emerge. The eggs are deposited on end in the cells, and are inclined toward the opening, so that any of the insects can emerge without disturbing the other occupants of the oötheca or of their own particular suite. Of course two insects cannot emerge from one suite at precisely the same time, but one may follow promptly after the other in single file, so very little interference occurs under this system. This arrangement of the cells is clearly shown in the cross-section, Fig. 7-8. The provision of separate galleries and exits for every four insects seems a wonderful economy of Nature.[4] Thus when common environment or common age brings all of the occupants of the nest to maturity and ready for emergence simultaneously, the probable high mortality resulting from crowding around a common exit is avoided. This is why we can examine an egg-case in the early morning and find not a trace of life, return in fifteen minutes and find the top literally teeming with struggling nymphs. Figs. 5 and 6

[4] For the method of making the egg case, see p. 40.

present the longitudinal section of the egg-case and show one room of each of whole number of suites. Fig. 5 still contains the empty egg-shells left by the emerging insects; in Fig. 6 they are for the most part removed. Figs. 1 and 2 are horizontal sections near the bottom and top (floor and ceiling) respectively. Fig. 1 shows distinctly the arrangement of the cells in cross rows (cf. Fig. 4) which, with their galleries (Fig. 2) meet at the center of the structure in an obtuse angle. Here they are dovetailed together in such a manner as to present a "braided" appearance along the crest of the case, each fold of the braid being a flap, or the trap-door of one of the galleries. Figs. 3 and 4 show horizontal sections of the egg-case through the middle, with and without the egg-shells in the cells. All of the horizontal views show the row of marginal cells surrounding the entire mass, and the heavy partition separating these from the egg-cells proper. These are present in all oötheca but are never used for oviposition. The purpose of these unoccupied marginal cells is not readily understood. We know that the egg-cases are cemented to flat surfaces; this would give ample protection against cold from the bottom. On the top we find the empty galleries which form an air-chamber between the outside covering of the case and the eggs. May it be that this row of unused cells is an adaptation for the lateral protection of the eggs from the cold or perhaps from the attacks of parastic impostors? Of course this is distinctly a southern species, and usually does not live above 40° latitude, and other members of this group are tropical. It is not fully known just how exits are made in the egg-cases of other species; it may be however that this character is a relic from some ancestor which used lateral galleries for exits.

The Emerging Mantis.

In the spring of 1909, after the egg-cases had withstood the natural weather conditions of the winter, 39

were gathered. These gave forth their young at the usual time, at intervals between the 1st and 20th of June.[5] In a previous year's lot, when the eggs were kept indoors, hatching occurred during May, while a few egg-cases which were brought into the living room on December 13, and kept at a temperature of 52° to 78° F., and occasionally moistened, gave forth active nymphs on February 10.

The emerging of the mantis was observed in many cases during three seasons. In every case almost without exception the insects left the oötheca during the early morning. In many instances 6 A. M. found them already emerged, and very seldom did they leave after 8:30 A. M.

Sharp (1895), p. 247, says that the last eggs deposited are the first to hatch. In this species I find that the eggs are deposited just as the egg-case is being made, and consequently the eggs at the broad, rounded end of the case are the first deposited, although the difference in time is very slight indeed. If the last eggs laid are the first to hatch, we should see all the emerging insects come first from the pointed end of the case. As a matter of fact, some egg-cases bring forth all of their young simultaneously and others on two, three or four mornings, but all of my observations lead to the conclusion that in this species the emergence of the nymphs occurs without any regard to the priority of the deposition of the eggs.

One may examine a number of egg-cases at perhaps 6 A. M. and find them apparently "dead as a door-nail;" return in a quarter of an hour and find them teeming with struggling young, all of a honey-yellow color. Struggling young—yes, each one laboring to work its way out of the egg-case and then struggling to free itself from the bag-like membrane which encloses the body and is in turn attached by a silken thread to the bottom of the cell from which the nymph has just emerged.

[5] Riley recorded in 1869 that the eggs hatched in this locality between June 10th and 20th. It is interesting to note that this date persists so exactly after forty-three years.

JUNE, 1909.

Egg case known as	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total.	Parasites.
A	63			26	1	1																	91	None.
B		27			32	3				5													67	None.
C		20		23	45	7					2												97	15 P. Mantis on June 18.
D				2	44	1		34		4													85	None.
E						92			7			1											100	None.
F						105		3	7			1											116	None.
G								60	13			3											76	None.
H								138		1			1										140	None.
I									109			1											110	None.
J										105		2											107	None.
K										63				2									65	None.
L										85		1											86	None.
M										51													51	None.
N										100													100	4 P. Mantis on June 21.
O										108													108	None.
P										84			1										85	None.
R										33			2						1				36	None.
S										5													5	None.
T													103		2		2						107	None.
U													1										1	None.
V													71				18				3		92	None.
W											92												92	None.
X													98					1					99	None.
Y													3										3	Heavily parasitized.
Z												2											2	Heavily parasitized.
A A															108								108	None.
B B															1	3	3		1				8	Infested by larvae of Anthrenus
C C																	44						44	June 19 & 21. 25 P. Mantis.
D D																	1						1	None.
E E																	94		3	2			99	11 P. Mantis on June 20.
F F																	77				2		79	None.
G G										5													5	None.
H H																							0	None.
J J																							0	None.
K K																							0	None.
L L																							0	None.
M M																							0	None.
N N																							0	Entirely parasitized.
O O																							0	60 P. Mantis on May 25.
	63	47	0	51	122	209	0	235	136	649	94	11	280	2	111	3	239	1	5	2	5	0	2265	

The accompanying table shows the number of insects that hatched each day from each of the 39 egg-cases. It will be seen that in just about one-half of them practically all of the occupants emerged at one time, with only a few stragglers, and that in the remainder the emergence continued through two or three mornings. The mean as well as the mode of emergence falls practically upon June 10.

A number of egg-cases were partially or entirely parasitized by Podagrion mantis. In some cases these parasites emerged before and sometimes after the usual time for the emergence of the host. They do not leave by the openings provided, but bore their own exits in the top and sides of the case. These holes are to be clearly seen in Y, Z, BB and NN in Pl. XV. Not a great deal is known of the life history of this Chalcid. The eggs are deposited in the egg-case in the fall and the adults emerge during the following May and June; just how the parasites spend their life from this time until the following September or October when the oötheca are again deposited and hosts supplied would be an interesting discovery. The fact that they are mature at emergence would lead one to conclude that they should be ready at once for mating and oviposition.

A few were infested by the larvae of *Anthrenus* (sp?). Whether these beetle larvae feed upon the oötheca as well as on the living eggs is not known, but at any event they injure the egg-case sufficiently to destroy the developing embryos.

Four egg-cases, while apparently not parasitized, gave forth only 5, 1, 1 and 5 insects respectively. Five others of apparently similar condition produced no young whatever. I suspected that these latter ones contained infertile eggs, and later in the season discovered that unfertilized females construct normal egg-cases.

Our table shows the greatest number to hatch from any one egg-case to be 140 and the minimum 0 in seven

cases, making an average of 58 for the entire lot. If however we take into account only the twenty-one perfectly good and normal egg-cases we find the minimum 36 and the average 91. These figures are, of course, for the emerging nymphs and not for the eggs. A. A. Girault (1907) opened 20 cases in November and counted the eggs. He found the numbers to range from 49 to 115, with an average of 88. The close agreement of Girault's average of eggs in November and mine for the emerging nymphs in June shows that there must be a remarkably low elimination during this stage, in unparasitized egg-cases.

The eggs and nymphs while in the oötheca are of a yellowish color, excepting that for about a week before the time of emerging the eyes of the embryo are highly pigmented. And at about this time, the distal part of the femur of the hind pair of legs, and a small portion of the head between the eyes, are of a brownish red color. The abdomen is also very slightly so marked. After the insect emerges these markings are conspicuous. Cockerell (1898) who has written upon species of this genus (either *S. carolina or S. limbata*) says that "the eyes are at first sage green, but soon after the emergence of the insect they become blackish." In our species, not alone at emergence are the eys black, but for some time before as well. To be exact, when the egg-cases were opened on May 15, the eye spots, were but slightly pigmented; on May 22, they were very much so, and became more and more intense from day to day. Thus pigmentation of the eyes occurs from about 15 to 30 days, before hatching.

Upon breaking the walls of the egg-case shortly before hatching, one finds the young nymph attached to its cell by a short silken thread. This thread seems to leave the rear end of the body and can be drawn out to a considerable length with a needle. By observing the egg-cases early in the morning on the day of emergence, one

can see the tiny heads pushing their way up out of the "trap-door." By a series of backward and forward movements the insect rises higher and higher out of the cell, until it lies entirely on the top, where it rests quietly for a moment as if preparing for the ordeal of shedding the membranous, sac-like covering which encloses the entire body.[6] As the insect rests one can with the microscope see the two silken threads which seem to leave the cerci, and which soon converge into one heavier thread which apparently leads back to the floor of the cell from which the little nymph has just emerged.

The insects just after leaving the egg-case are shown, enlarged, in Figs. 1 to 5, Pl. XVII. They are still enclosed in the tightly-fitting, membranous sac which is held in position by the silken threads (Fig. 2). After a few moments the thorax begins to enlarge and a lump appears behind the head, which becomes larger and larger until the condition shown in Figs. 1 and 3 is reached. As this lump increases, the head bends further and further downward against the ventral surface (Figs. 4 and 5), causing the prothorax simultaneously to become elongated and rounded until we see the rupture of the tegument; the enlarging of the prothorax seems to push the skin apart causing an opening, and as this organ expands the old skin is pushed further and further back. This bag-like membrane encloses the entire organism, and holds the legs and antennae fast, close to the ventral surface of the body.

This shedding process was long thought by many naturalists to be the first ecdysis, but as neither the antennae nor the legs cast their skin, but the membrane enfolds them as well as the entire body, I do not see how this can hold; neither can this covering be the egg-shell, for we have seen that the egg-shell is left in the egg-case at emerging. In again referring to the casting of this

[6] The hind pair of tarsi protrudes from the sac-like covering, and may have aided the insect in emerging.

membrane immediately after hatching, my observations are entirely in accord with those of Cockerell who, in criticising Sharp, points to the fact that the shedding of this envelope is not a real ecdysis. As I have already shown, this membrane binds the appendages to the body. When this is shed, it merely liberates these organs. Were this a real ecdysis, we should see the skin peel from the legs and antennae separately, as well as from the body.

The skin splits and the prothorax becomes quite large, and in so expanding frees this organ and the head. In examining the old skin we find that part which immediately covers the head to be more heavily chitinized; this "cap" surely protects that organ as the nymph butts its way out of the egg-case.

The animals seem to have enlarged considerably within the few moments, and the head and thorax are entirely free. The skin thus far removed hangs beneath the ventral surface of the prothorax with that heavily chitinized head covering distinctly visible. The antennae are tightly stretched along the ventral surface, terminating somewhere near the anus, reminding one of two tightly stretched telegraph wires. The legs are also visible through the transparent membrane, all nicely folded close against the abdomen.

It is now necessary for the remainder of the covering to be removed, and this is done, strangely enough, by the antennae. I have already shown that the head bends downward and that the two antenna which issue therefrom are tightly stretched along the ventral surface, terminating near the cerci. The head by a series of bendings backward and forward alternately tightens and loosens these cords (antennae). With each backward and tightening motion the skin slips further and further back until the legs are free; these then assist in removing the skin until it slips off over the cerci. The insect is then entirely free and runs away with astonishing

sprightliness, leaving the sac still attached by the short silken thread to the egg-case. The mantis as it leaves the old skin is almost twice the size of the emerging form, even though this entire process occupies but eight to fifteen minutes from the moment the bead-like head pushes through the trap-door to the time when the nymph scampers away from the newly-shed covering. The insects hang to the oötheca by means of the threads for only a very few minutes and not,as Sharp says, "for some days until the first change of skin is affected." When one views the shrivelled little sac left hanging from the egg-cell, one marvels that it really was sufficient to cover the entire insect. The length just at emerging is about 5 mm., and a very few minutes later, after the envelope has been removed, it has increased to about twice this size.

The eggs all develop in their cells with the part which forms the head nearest the exit, so the emerging insect will have little difficulty in pushing its way through. Either the eggs must be deposited right end up along with the making of the case, or the egg-mass in the early stages of its development must turn about in the shell and thus come to a proper position. Gravitation cannot be the controlling agency in this case, because the egg-cases are built at all angles with the direction of the force of gravity. Out of eighty egg-cases observed during two years, I found only one exception to this position of the egg. In this instance, while many tiny heads were appearing all over the crest of the case, from one cell the caudal end of the body and a pair of tarsi appeared. The nymph made a brave struggle to emerge, but after a few minutes it was found dead.

The Moulting Process.

How often the mantis moults is not precisely known. Howard (1901) says it moults at least three times; most

other writers on this species mention nothing about the process. Sharp, in speaking generally of members of the family Mantidae, says that they moult six times. In all of my work with this insect, I have never been able to carry one individual through from the first instar to the last while in confinement. Their rearing is rendered very difficult by the facts that they are entirely carnivorous, attacking only live prey as it moves about, and it seems they also require a variety of diet which cannot be supplied at all times, especially when large numbers are cared for and each insect on account of its cannibalistic habits must be kept in a separate cage. During one season when an attempt was being made to ascertain the exact changes in size and color of these animals, about a hundred of the ordinary household fly-traps were obtained, a mantis placed in each, and the bottom compartment of the trap daily filled with stale beer. This attracted the flies which would eventually find their way to the apartment above which was occupied by the mantis. This arrangement was of course a sort of self-feeder and gave us but little trouble, but the insects never lived long under these conditions. Whether it was the lack of variety of food, or the diet of intoxicated flies that caused their death is not known. Only recently it has been discovered that the mantis nymphs require water, and greedily partake of any offered them on a small brush or sprinkled on plants in the cage. But although it was impossible to carry even one insect through its entire life cycle, enough data were procured to show conclusively that the animals go through at least six moults exclusive of the shedding of the membranous sac just at emerging.

The date of hatching of the insects is from June 1 to 20. The following notes on the time of moulting and the size and color of the insect at that period will help to clear up this problem of the number of moults and the rate of development.

No. 100. June 22, this green insect was taken.[7] After moulting the same day the color was still entirely green; length, 15 mm. July 3, moulted; color, legs green, dorsal thorax and abdomen greenish with light brown patches; length, 19 mm. July 7, entire dorsal surface light brown. July 12, entire insect straw-colored excepting all the legs which were still greenish. July 13, moulted; entire body and forelegs brownish; two pairs of hind legs still green; forelegs not as decided brown as the body, but showed a transition stage between green and brown; length, 22 mm. Aug. 8, moulted; all brown excepting hind legs; length, 28 mm.; died.

Thus we see that this insect showed the following rate of development for the part of its lifetime under observation:

June 22, 2nd moult[8].....15 mm.
July 3, 3rd moult.....19 mm.
July 13, 4th moult.....22 mm.
Aug. 8, 5th moult.....28 mm.

Whether a moult occurred before the length of 15 mm. was attained on June 22, and whether any more would have occurred after Aug. 8 and 28 mm., had the insect lived, must be supplemented from notes on other individuals.

No. 110. June 23, taken; color green; length, 14 mm. July 5, moulted; green with brownish spots on the dorsal surface of first three abdominal segments; length, 21 mm. July 14, moulted; straw-color, with only four hind legs green; length, 25 mm.; died.

So while only two moults could be observed in this insect, they correspond rather nicely in dates and size with those of No. 100.

No. 111. June 23, taken; yellowish green; length, 16 mm. July 1, moulted; yellowish green; length, 18 mm. July 3, no moult observed, but length was 22 mm. July 10, moulted, entirely light brown excepting two pairs of hind legs and coxae of forelegs; length, 25 mm.

No. 108. June 23, taken; entirely green; length, 16 mm. July 1, moulted; all light brown excepting coxae of front legs and all of the four hind legs, which were green; length, 18 mm. July 12, moulted; entirely medium brown excepting legs as described before; length, 25 mm.; died.

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[7] The colors and changes will be again referred to later.

[8] For first moult at 10 and 11 mm., observed on other insects, see p. 16.

No. 130. July 7, taken; entirely green; length, 20 mm. July 12, moulted; still greenish but not a clear color; length, 27 mm.; died July 16.

No. 102. June 23, taken; color, green; length, 12 mm. June 23, moulted; green; length, 14 mm. July 3, moulted; greenish straw color excepting two hind pairs of legs and coxae of forelegs which were still completely green; length, 17 mm.; died.

No. 103. June 23, taken; green; length, 15 mm. June 30, moulted; dark straw color; length, 18 mm.; died July 11.

No. 104. June 23, taken; entirely green; length, 12 mm. June 30, moulted; abdomen yellowish, dorsal prothorax light brown, remainder green; length, 16 mm. July 9, moulted; entirely straw-colored excepting tibia of middle pair of legs, which were still green; length, 20 mm.

No. 109. June 23, taken; green; length, 16 mm. July 3, insect had probably moulted and skin been lost in the leaves; color now dark straw-color; length, 18 mm. July 5, completely straw-colored, with just a faint trace of green on tibia and femur of two hind pairs of legs. July 12, moulted; light brown with heavy black spots on legs; length, 22 mm.; died.

No. 101. June 23, taken; green; length, 12 mm. June 26, moulted; green; length, 15 mm. June 28, part of abdomen yellowish brown. July 3, dorsal and ventral part of abdomen dark brown, dorsal surface of thorax gradually changing to brown; head, all the legs and the ventral surface of thorax still grass green. July 9, moulted; entirely brown excepting the greater part of each of the four hind legs and coxae of forelegs; length, 18 mm. July 22, moulted; color same as before; length, 22 mm.

These notes made during 1911 support with only very slight variations the phenomena noted above, pointing to the conclusion that four moults occurred between June 22 and Aug. 8. From the table below it is evident that another moult (the first) occures previous to that time, when the insect is 11 to 14 days old.[9]

Hatched.	Moulted.	Length.	Color.
June 11	June 22	10 mm.	Yellowish
June 7	June 21		Dark brown
June 7	June 21	11 mm.	Greenish
June 11	June 24		
June 11	June 24		
June 11	June 24	10 mm.	Head, thorax and appendages light green; abdomen blackish
June 11	June 21	11 mm.	Light green
June 11	June 24	10 mm.	Green with black spot on prothorax where legs join

[9] From notes made in 1910.

This, with the four moults previously described, gives us five moults. At this fifth moult the wing pads are highly developed, and the insect measures from 28 to 32 mm. in length; it is now in the instar immediately preceding adulthood, when one more moult completes the process of development, and the insect attains a size of 48 to 60 mm.[10]

It is hardly possible that a moult could have escaped observation. Hence we may feel confident in concluding that there are at least six months and seven instars in the life cycle of our mantis.

Pagenstrecker (quoted by Packard, Text-Book Ent., p. 616), finds that the Mantis religiosa moults seven times, having eight stages in its development, including "that before the amnion is cast." Hence we arrive at the same conclusion, for in our species we have six ecdyses and seven instars exclusive of the shedding of the envelope just after emerging, which, as we have seen, can hardly be regarded a true moult.

Of course when circumstances are such that individuals cannot live to maturity in confinement, and since sex cannot be distinguished until late in the insect's life cycle, it has not been determined finally whether males and females pass through the same number of moults in their development. It may be possible however that the conditions of confinement, food, temperature, etc., may influence the size of the insect and the time of moulting, but it seems hardly probable that it could cause a variation in the regular, established number of moults.

It is extremely difficult to handle a delicate and perversely active little nymph which insists upon rearing up the abdomen in a semicircle while he is being measured. The measurements from life were all made under these difficulties, and may err slightly either way.

[10] This measurement is for adults that were not confined in the earlier stages.

In 1910 the first adult female appeared on Aug. 16. In 1909 the first gray female came to maturity on Aug. 3 and the first green one Aug. 9. All these were taken in the open, where development would probably be a little more rapid than in confinement.

The nymphs of the two sexes are very similar and cannot be distinguished by appearance until the instar just preceding adulthood. In the adults, the difference in the size and shape of the bodies is so great that they might easily be mistaken for two distinct species. The male has a long, slender body completely covered by the wings; the body of the female is much broader and the wings are aborted so that they cover only a part of the body.

Method of Shedding the Skin.

The method of moulting is the simple one characteristic of most Orthoptera. The skin splits along the prothorax and the insect works its way out; usually the head and prothorax are pushed through the opening first, and the abdomen and legs are freed later. Frequently the smaller nymphs hang with the hind pair of tarsi interlocked around a twig while undergoing this metamorphosis.

In Pl. XVIII, Fig. 2 we see a twelve-day insect (¾ natural size and enlarged) undergoing its first real ecdysis. The body is wholly free and the insect is struggling to extricate its legs from the old skin. Pls. XI, XII, XIII show the nymphs after the fourth moult, when the wing-pads are first apparent.

The mantis all hatch at about the same time and, when the insects are free in nature, the whole population seems to moult at about the same perid, so the rate of development of all the individuals is kept about parallel. In other words, when one finds mantis, say in June or September, they are almost always all very much alike in size and form. Hence we do not find, as Rathvon (1862) records, that the "mothers often feed upon their

own young,'' for the parents have all died the year before, nor do the adults ever get a chance to feed upon nymphs, for the time is short when the instars overlap. Thus we seldom find the insects in more than two stages at the same time.

Food Habits.

The mantis is entirely carnivorous. In this respect it differs radically from the other members of the family Orthoptera. It will attack only insects in motion. The very small nymphs in confinement were fed upon plant-lice, while the larger ones were fed flies, grasshopper nymphs, small crickets, etc., although where many mantis were caged together their principal diet seemed to be one another. The nymphs are cannibalistic, and in the adults, the females alone seem so. I have seen them devour one another as well as eat the males, but never yet have I seen an adult male attack either a female or another of its own sex. Whether the male nymphs are cannibalistic could never be ascertained with absolute certainty because the sexes are indistinguishable in the earlier stages.

The mantis have been observed to feed upon the following organisms:

> Nymphs of cockroaches; (*Blatta orientalis*) the white ones four days old were highly relished. Nymphs and adults of the German roach *Blattella Germanica.* Colorado potato bugs, discarding hard parts. Larvae and adults of *Grapta interrogationis* Fab. Hairy caterpillars and others. The common tomato-worm (larva of the Sphinx-moth). Aphids. Male adults of the Bag-worm (Lepidoptera). Ants. Adults of the May-fly (Ephemeridae). Honey-bees. House-flies. The cucumber beetles *Diabrotica* 12-*punctata* and *Diabrotica vittata* were greedily devoured. Blister Beetles, *Epicauta pennsylvanica* (De G). Pennsylvania soldier beetle, *Chauliognathus pennsylvanicus* De Greer. Also *Chauliognathus*

marginatus Fab. Lace-wing adults, *Chrysopa* Sp. Crickets. Cabbage butterflies, *Pieris rapae.* Nymphs of grasshoppers and locusts. Frog, about one-half inch in length, was held in the forceps and kept in motion before the mantis. The frog was seized and about one-fourth devoured.

Many kinds of food insects were offered to the mantis upon forceps. Potato-bugs were refused when the insect was not terribly hungry; robber-flies (Diptera) and stink-bugs (Hemiptera) and very large grasshoppers were always rejected. The insect never hesitated to jump at the forceps bearing palatable bits, and never delayed to back away when a distasteful morsel was offered. From this I would infer that the sense of smell or of sight, or both, must be highly developed.

A bag-worm larva removed from the cocoon was offered to a number of mantis, but in every case but one it was refused. In this case the mantis at first ran away very fast from the forceps carrying the larva, but stopped and turned its head around, and when I insisted again it grasped the "bug," put it to its mouth and immediately dropped it to the floor in apparent disgust.

One mantis was observed making an attempt to grasp a wasp (*Polistes Sp.*), but after eyeing it for a few seconds the mantis jumped away. I followed with the Polistes in the forceps, but it would dodge from one side to the other when the wasp was thrust directly in front of its mouth. In a later experiment, a mantis ate the head and part of the abdomen of a male wasp (*Polistes Sp.*).

A mantis attempted to devour a white moth (family Arctiidae) by biting into it at the thorax near the basal part of the left wing. After the wing had been severed the insect continued its efforts to penetrate the hard chitin. Making no headway it left the insect clinging to the wire screening. After about five minutes it returned and again began to bite away at it at the same

spot; after two minutes persistent effort it became disgusted and dropped the moth to the floor. Taking it in my forceps I again offered it to her repeatedly, but she persistently refused. This mantis must have been pretty hungry, but still had not the "ability," "wisdom" or "foresight" to know that by trying at a point further down, the soft parts of the abdomen would be found. My second insect made a like refusal, but in a third experiment the mantis began by devouring the caudal end of the moth, eating headward, and in fifteen minutes it had consumed the entire insect. Of course it was probably wholly accidental that the last mantis found the soft parts first.

A small nymph, aged 17 days, was seen to feed upon two small Hymenoptera one morning. At 6:30 it pounced upon one, and holding it fast in the forelegs began to devour it. After two and a half minutes, whatever remained was held in the mouth while the second was seized; this was held tightly while the first was being devoured,—and this without any help from the forelegs in holding the first. This was entirely eaten in five minutes, immediately after which, the second was consumed in eight minutes. Perhaps the first was eaten hastily to prevent the possible escape of the second.

A marked mantis, whose entire prothorax was thickly covered with green paint, was devoured, paint and all, by a comrade, and so far as I could see agreed perfectly well with the insect.

The adults have the most human characteristic of breaking large prey in two parts, one "hand" holding one portion to the mouth while the other tightly holds the second course in readiness.

While the nymphs are greedy eaters, I believe that the adults, at least the older ones, can get along for a considerable time without food. At one period of three days early in September when food was very difficult to obtain, out of 28 caged specimens which had no food, only

5 died; hence we have no reason to conclude that even these died from this particular cause. The adult males require little food, and in confinement seem to live as long as the females.

The males do not eat while in copulo, since their forelegs are used for clinging. The females, however, having these appendages free, lose no opportunity to grasp a choice morsel.

Again referring to the cannibalism of the mantis, Pl. VII shows a gray and a green female in combat to the death. The spiny forelegs of each are locked about the thorax of the other, and the head of the fair one (green) is about to sever.

Enemies of the Mantis.

Small red ants were once accidentally introduced into the cages along with the aphis. Instead of the carnivorous nymphs eating these also, the ants although much smaller, immediately fell upon them, first severing the legs at the joints and then dismembering the other parts of the body, while the struggling mantis tried to get away. It was at first thought that the ants behaved thus in order to protect their dairy, but it was later discovered that they carried away all the parts of the dead mantis, evidently cherished as palatable bits. The mantis when older, however, reversed the attack and greedily devoured the ants.

Another grave enemy to the eggs is the Podagrion mantis already referred to, and in all probability the larvae of Anthrenus sp. also. A spider was once seen devouring a mantis nymph. What part birds play in keeping their numbers in check is unknown, but both sexes, dead or alive, were greedily eaten by poultry, and even the egg-cases, both old and new, were likewise devoured.

Upon one occasion when I was testing the ability of the mantis to capture and kill honey-bees, one was tied

near the bee-hive entrance by a silk thread around the prothorax. The mantis received two severe stings on the side of the abdomen where the chitin is very thin. The animal bent the body around in a circle and bit frantically around the wounds, perhaps injecting saliva —I could not discern. An hour later each wound was covered by a drop of fluid and that side of the abdomen was much swollen. The insect survived, however, and soon behaved quite normally, mating three days later.

It was noticed that the mortality was unusually great at two or three days after emergence. Food was plentiful, and cannibalistic habits were not carried on to a great extent. It was discovered by the aid of the microscope that the insects at the time of emerging, as well as the egg-cases, were teeming with mites,[11] which in all probability caused their death.

Color.

We know that all mantis at hatching are of a light yellowish color, the eyes alone being pigmented. Within a few hours this color becomes darker. The color of the immature insects at any stage after the first moult is not constant, but varies from a grass green to a dark, mottled gray, almost black, and including a vast variety of dull yellows and browns. It frequently occurs that a single individual will exhibit many or all of these colors in varying combinations.

In the adult females we find the same conditions in the coloration of the body. In addition the wings are green, yellow or one of a variety of shades of gray, or mottled. Sometimes we find a brown adult female with green wings and sometimes a green one with brown wings. The males do not exhibit such a marked variety of color, but are usually extremely dark and the wings mottled, although a good many of them have green legs, and occasionally one occurs with green body, head and

[11] Identified by Dr. H. E. Ewing as *Pediculodes ventricosus* Newport.

appendages, but never yet has a male been found with green wings. In some of the males the wings are hyaline, but observation has shown that this condition usually exists for a short time after moulting and before the pigment is distributed. In many the two pairs of hind legs seem to acquire the darker color before the front ones do; many are seen with the hind legs dark gray while the front pair are still green. These are always in contact with the material upon which the insect rests, the dull, dark bark of trees, etc., while the front ones are held high in the air.

Near to the center of the wing is a highly pigmented and clearly defined spot which is very conspicuous in the green winged insects, but not so much so in the dark ones. The utility of these is not at once apparent, although one is likely to suspect at first thought that they are to give an aggressive appearance when the female raises her wings in the attitude of fight. When the insect is at rest, one wing partly overlaps the other sometimes covering this pigmented spot.

Little is precisely known concerning the regulation of colors in this insect, but it has hitherto been generally thought that the males were brown and the females green (Howard). Riley (1869, p. 170) says: "The green form is almost entirely confined to the female sex and seems to be the most common color of this sex when full grown." According to Scudder (1896) this dimorphic female was for a time specifically divided, the gray one being called dimidiata and the green one carolina. But in criticism of this he says that since the two forms occur in the United States he cannot see how they could be specifically separated, since there is no similar distinction in the male, which is never entirely green.

My own observations have fully satisfied me that the adult females appear not only in the green form (Pl. I) and in the gray (Pl. V)[12] but also in every gradation

[12] See also Plates VI and VIII.

and combination of these colors between these forms illustrated, and that these variations can be found in every stage of the insect's life cycle after the first moult. As already stated, the color of the male does not vary so greatly, but still green-bodied insects are found.

The color of the mantis certainly serves to protect it, even though the green insects are not always on green leaves, nor the dark ones on dull bark. The photographs nicely show how, when resting on foliage, their color seems protective, and their appendages blend well with the twigs. In spite of the fact that, so far as I can see, no discrimination is shown in the selection of their background, the insects blend beautifully with their surroundings; their form as well as their color seems to make them inconspicuous amid the lights and shadows of the foliage. Thereby they are protected from the attack of enemies and aided in successfully stalking their prey. Of course that does not necessarily mean that their coloration came about on that account. Perhaps this phenomenon can best be explained by Beddard, who says: "It is often not easy to find a sixpenny piece, which has been dropped on the carpet, but the reason for this is, not that the coin is protectively colored, but that any small object no matter how colored is difficult to discover amid a variagated environment."

In fact the younger nymphs, with their wings not yet developed, were harder to find than the adults. Usually when insects were needed, sweeping the shrubbery with a net had to be resorted to, although both nymphs and adults were not infrequently to be found stretched across some bright flower waiting for insects, and were extremely conspicuous, but on such plants as the tamerack, iris, hops and canna, the green ones were always inconspicuous. Blending so nicely with their environment may be instrumental in securing their prey, but to what extent this protects them from birds, toads and other enemies is not known, although Di Cesnola's experiments

upon the European species point to the conclusion that it does afford protection.

One wonders about the value of protective coloration when one sees a dark gray female, resting on a green tamarack, very conspicuous indeed, greedily devouring one which is green. But again in contrast to this, when the green nymphs are at rest on the clematis or hop vines and an attempt at their capture is made, they dart from leaf to leaf, quickly turning to the under side, then drop to another and vanish in less time than it takes to tell.

Color Change.

We have seen in the chapter on the moulting process that the insects at hatching are all alike of a light yellow color. Just after the first real ecdysis they occur in many colors, the two extremes being distinct green and dark brown. We have seen that green insects gradually change to brown;[13] this may be due to the color of the environment. My attention was first attracted to this by the following observations upon nymphs and adult females which were kept for other notes.

In the first instance the cage contained no potted grass nor green things of any kind, and the insects could rest upon nothing but the almost black wire screening of the cage. It seemed to me that the ventral surface of this adult female—the part in constant contact with the screening—became darker from day to day. Whether this happened on account of the environment or in mere coincidence is not known, but we must not fail to consider that this was a full-grown, winged insect when placed here.

In the second case the adult insect when placed in the cage was entirely green, both body and wing. After being there for thirty-four days until its death, we found the wings and the abdomen under the wings still green,

[13] See pages 15, 16.

shading into brown at the exposed parts, while the ventral and lateral parts, as well as legs, head and thorax,—in fact all constantly exposed parts—were dark brown.

On another occasion several green females in the next to the last instar were placed in a breeding cage together with several pots of growing grass which would serve as a background and foothold for both the mantis and their prey. During a heavy shower the cages were taken into an outbuilding, and fortunately or unfortunately they were forgotten there for about a week. During this time the grass died and turned straw. When they were discovered the mantis had devoured one another, but the two survivors which were found with difficulty had become adult, and there they were—body, legs, wings and all just the right shade of straw color.

This led to other work with the insects. The difficulty of maintaining in one's own home a large number of animals which are cannibalistic, voracious and carnivorous, and which require a variety of living food can perhaps be imagined.

In an experimental way I tried to find just how and why the colors changed and if environmental conditions were the sole causal factor. For three years the work was carried on with not at all encouraging results. The first year lamp-chimney breeders were used. The mortality was great owing to the difficulty in the regulation of moisture and temperature. The second year a number of home-made wire cages were used and a large number of individuals placed in each. The extreme cannibalistic tendencies reduced the numbers to almost nothing, but the work still gave a clue to what were the tendencies of the adaptation of the animal to its environment. Later about a hundred fly-traps were procured and set up as described elsewhere in these pages.

The work will probably be carried on for another season, but enough data have been gathered that we can

confidently state in a preliminary way at least these conclusions:

1. The green nymphs are capable of changing to dark gray or brown when the environment is dark.

2. The green insects will in all probability remain green when the environment is favorable to that color.

3. When once the gray color is acquired it is permanent despite any environmental conditions.

Poulton[14] says that "all green colouration without exception is due to chlorophyll, while nearly all yellows are due to xanthophyll." Tower in his work on Colors and Color Patterns in Coleoptera goes more into detail on the coloration of Orthoptera. He says that in the Orthoptera the prevailing colors are blacks, browns, greens, yellows and rarely reds; the browns, blacks and some of the yellows are cuticular colors; the reds and most of the yellows are hypodermal. The Orthopteran forms are largely vegetable feeders and "the greens and yellows are centainly in part derived from plant pigments." Thus the two color authorities reach the same conclusion, that the greens and yellows are derived from plant pigments. But here a mantis, an Orthopteran form which never in its life eats anything but animal food, attains precisely those colors. It is true that this insect, while entirely carnivorous, might acquire a certain amount of chlorophyll by feeding upon insects which in turn are phytophagous (caterpillars, aphis, etc.) and thus develop the green color, but in that event why should this effect follow in only a part of the insects when all of them live upon practically the same food supply?

To assume that the coloration of the mantis is a vestige from the time when their ancestors were vegetable feeders is far from satisfying.

[14] Quoted by Vernon, Variation in Animals and Plants, p. 291.

Mating Habits.

The very fact that the female mantis almost always devours her mate while the pair are in copulo, and the male unresistingly clings while he is slowly being eaten, makes the mating habits of this species arouse more than ordinary interest.

Pl. II is a very good photograph of a pair in the characteristic position of mating. The female here illustrated is green, while the male is an ordinary dark insect. The illustration nicely shows the general structural dimorphism of the sexes, as well as the comparative size of the antennae.

That the males seek the females I have not a doubt, for in many cases they were found clinging to the outside of the cages containing the latter. The insects display so much individuality in their mating habits that it will be well to give the details of the behavior of a few typical individuals during this period.

Experiment 1. Aug. 14, 8:00 A. M., a male and a newly-matured female were placed in a large breeding-cage. A half-hour later the female was walking about the ceiling of the cage, gracefully mounted by the male (but not in actual copulo), who tightly clutched her around the prothorax with his forelegs. The female was greedily devouring hairy caterpillars. The entire day was spent in slowly walking thus about the ceiling. Actual mating occurred at twilight, after a courtship of about ten hours, during all of which time the male seemed in quite the proper position. They separated some time between midnight and 6 the next morning, but at 10:30 the male had again mounted, and at 12 o'clock noon they resumed copulation and continued throughout the afternoon, severing some time between 7:30 and 10 that evening. Again the next morning, Aug. 16, at 6, the male had mounted for the third time, but actual mating did

not take place until the afterooon of the day following, and they severed early in the evening. Aug. 18 and 19 they were observed frequently, but no activities occurred during these two days; it was not until noon, Aug. 20, that the pair again mated.

Aug. 21, 7:00 A. M., the pair found separated; 2 P. M., male mounted on female; an additional male introduced.

Aug. 22, 7 A. M., all found separated; 7:30, one of the males had mounted. Aug. 23, 6 A. M., all separated. Aug. 24, one male mounted. Aug. 25, 6:30 A. M., female again in copulo with one of the males; 4 P. M., severed, but retaining position of mounting. Aug. 26, 6:30 A. M., this pair had resumed mating; 3 P. M., severed. Aug. 27, 7 A. M., found first egg-case which had been deposited during the night.

Thus this female mated six different times and remained so about forty-five hours and deposited one egg-case during the first 14 days of its adult life.

The pair remained separated all day (Aug. 27) until 9:30 P. M., when they were again found in copulo, after a lapse of less than twenty-four hours since the deposition of the egg-case. No observations could be made the next day, but on Aug. 29, 6 P. M., this female was again mounted by one of the males, which condition continued until the evening of Aug. 31. Thus for three days she carried him without actual mating. Why this conduct unless another egg-case was soon to be deposited? Was the male inefficient, and if so, why was he not devoured? Was the female still exhausted from egg-laying five days before? At this time this male was removed and another which appeared to be as yet unmated was placed in the cage. Only five hours later, this pair was found to be in actual copulo; this indicates that probably the other male was exhausted. During the following forenoon, Sept. 1, they separated. On Sept. 2, 6 A. M., the lifeless remains of the male were found, with the abdomen entirely eaten away. Why did the female carry

the useless mate for three days without molesting him, and then turn around and attack one which might yet have been of some use?

The female was left alone until Sept. 4, when a new male was introduced. The next day he was found dead, with no signs of having been attacked by the female. On Sept. 6 still another was introduced, but no observations could be made until Sept. 10, when no male was found; evidently he also had been devoured.

The female was left alone and unobserved until Sept. 13, when the second egg-case was found to have been very recently deposited. The next day she was dead.

We learn from this experiment that the female mates many times with one or more males, that two egg-cases may be deposited, and that the duration of adult life was, in this case, 34 days.

Experiment 2. Aug. 14. The cage contained two adult females and one in the instar just preceding adulthood. A male was found silently resting on the outside of the cage; he was grasped by the long prothorax and gently ushered inside. But his welcome was not a gracious one, for the next morning he, as well as the nymph, had been eaten. Another male was placed with the two remaining females on the afternoon of the 16th. Early the next morning he was found in mating with the gray female; they separated from about noon until 3 o'clock, when they resumed mating until some time in the night. The next day, Aug. 18, the male turned his attentions to the green female, mating with her in the afternoon. The following day all were going about singly until 5 P. M., when the gray female mated for the third time. This gray one mated again on the afternoon of Aug. 21, and the green one for the second time on Aug. 22. On the 24th the green female carried the male for some time but actual copulation did not take place until the 28th. At this time the gray was the successful rival, and she concluded this her fifth mating, with devouring her mate.

None other could be found to succeed him. On the morning of the 30th, two new egg-cases were found. It seems probable, though uncertain, that each female had deposited one, for further observations proved that usually an interval, with copulation, occurs between the making of the first and second egg-case.

On Sept. 1 another male was secured and placed with them. No observations could be made until the evening of the 3d, by which time he had been eaten. On the next morning the green female was also dead, but the death had been a natural one as no marks of violence could be found on the body. From this time forth no males whatever could be secured, and the gray female alone remained. Ten days later a newly-made egg-case was discovered. This female was not observed in copulo between the first and second egg-laying, although this may have occurred during my absence from the experiments during the first of September. This new oötheca was placed flush with one of the first ones, slightly overlapping it, as if intended for its continuation. Did the insect recognize its first effort and attempt to enlarge upon it, or was the choice of location purely accidental?

This insect was observed daily until its death Oct. 8, and fed occasionally, but it required less food from day to day as old age came on. After the chilly nights she would be found stretched upon the wires of the cage quite as if dead, but with the warm rays of sunshine she would soon revive.

Experiment 3. Aug. 13. A male and a gray female were caught in the garden and placed in a cage. Soon the female was observed to be carrying the male, and so they walked about during the entire day, the female for diversion devouring many flies; not until sunset did actual copulation take place. This mating continued for an unusually long time, until between midnight and morning of Aug. 15, or more than eighteen hours. They mated again on the 17th, from early morning until late

afternoon, and from the middle of the afternoon until night of the 18th, and after that appeared quite indifferent to each other until the afternoon of the 21st, when they again remated for a few hours. They went about singly for the next three days, after which the male mounted for a few hours in the evening, but did not accomplish mating. By morning he had been dislodged, but in the afternoon he again persistently remounted. He was carried thus by the female all day, and it may be all night too. The next morning revealed an interesting double surprise; there was an unfinished egg-case made during the night, and the pair was again in copulo. Whether she made this oötheca with the male on her back, or whether he left her while she hurriedly constructed it and then insistently returned, is not known. The nest certainly offered the appearance of hasty or interrupted work, for it measured only 10 mm. in length and was not finished with the usual nicety of a gradual slope from the top to the base, but it had the appearance of having terminated abruptly. The oncoming of oviposition probably prevented copulation, for we know that the male was mounted and in readiness for the three days preceding, and that it occurred within a few minutes or at least a few hours after the egg-case had left her body.

They continued in copulo throughout the day, but were separated all of the next. On the morning of the 28th, it was found that an additional oötheca 22 mm. in length had been joined to the first one, during the night. We shall not venture to call this more than mere chance or coincidence, and yet this was the second instance of a mother mantis placing her second nest in close juxtaposition to the first, quite as though it were a continuation of it.

For the next two days each went about its own affairs, and on the morning of the 30th the male was gone, evidently having been devoured since escape was impos-

sible. From this time on the female was alone. On the morning of Sept. 10 she was found dead, but during the night before she died she had built another egg-case, a beautiful piece of work 30 mm. long. Shall we say that this female deposited three oötheca? Hardly, since the first installment was abnormal and either interrupted or made under difficulties and the second part soon added to it, and both parts together compared well in size with the second.

Experiment 4. Aug. 15. The pair mated almost immediately after being placed together in the cage at 7 A. M. At noon however they separated, probably on account of a heavy shower in which they were caught. During the next few days, ordinary uneventful matings occurred at the following times: from early morning until noon of Aug. 16, and from 9:10 P. M. of that same day until noon of the 18th; from early morning until noon of the 21st, and about the same hours on the 23rd. On the 24th, the male again mounted, but the female would not consent to actual mating, and the next morning she was found pleasantly devouring him. A new mate was at once supplied; at 4 P. M. he also mounted her, but again copulation did not occur. The next morning revealed that he likewise had been eaten and an egg-case had been made during the night. No new mate could be supplied until the evening of the 27th, and he very soon mounted. This time she carried him, without attack or resistance, for about eighteen hours before actual copulation occurred. In this respect the attitude of the female seemed very different after oviposition from just before. This copulation continued until some time in the forenoon of the 29th, when the male severed but did not dismount. He retained this position, without resuming mating, for almost three days, when at 4 P. M. on Aug. 31 he dismounted without any display on the part of either individual. This male was now removed and a new one introduced which mated with this

willful female in less than two hours. This continued until the forenoon of the next day, Sept. 1, and at 6 that evening she ate him. A new one was thrust in with her immediately, and before 9:30 she had accepted him as a mate. By the next morning they had separated. Copulation was repeated that night, Sept. 2, and again all day on the 4th. After this each went its own way, until the morning of the 7th revealed an explanation for this conduct during the past three days in the form of a newly-made egg-case. After this, copulation was promptly resumed early the next morning, but by 8:30 A. M. the male, already headless, was being slowly and calmly devoured by his mate, while he clung, apparently automatically, without the least effort of resistance. At 2 P. M. the leisure meal was still in progress and by 4 o'clock the entire body, excepting a wing, had been eaten. No other mates could be gotten, so henceforth her life was spent alone in the cage, until her natural death Oct. 10. During her entire life after her capture, 56 days in all, she took very little food, excepting occasionally a mate, and for the eight days preceding her death she ate nothing whatever.

Experiment 5. Aug. 15. A male and two females, a gray and a green, were placed in a cage. Mating soon took place with the green one. At 6 the next morning they had severed, but they reunited at noon and continued so until some time during the night. At 3:30 P. M. of the following day, Aug. 18, this male turned his attentions to the gray female. Mating continued throughout the evening, but early the next morning only her gray wings were to be found on the floor of the cage; evidently she had been devoured by her rival, for the adult males never attack members of either sex. The remaining pair were indifferent to each other, so on Aug. 20 a new gray female was introduced. The next morning however the male was found to have returned to his old green mate, but at 2 P. M. they separated. No activities whatever took place until the 23d, when the green female

was found to be again in mating, but the male was headless. The pair was chloroformed thus for a photograph (Pl. III), so further notes could not be made upon this experiment.

Experiment 6. Aug. 18, 7 A. M. A pair in coitu were found in the garden and gently placed in a cage. At 10 o'clock they had severed, but resumed mating at 3:30. At this time a gray female was introduced, and by 7 P. M. the male had left the green female for her. The next morning the male had severed but not dismounted; she carried him all day until 5 P. M. when copulation was again resumed. The next day he was only being carried again; he persisted in this position until midday of Aug. 21, when he was devoured. By the following morning the green female had also been devoured by her voracious companion. A new male was at this time placed in the cage with the remaining gray female, but no mating occurred during this or the three days following, and on the 26th he likewise fell her victim. But the next morning revealed an egg-case made during the night. The female was now left alone until a new mate could be gotten Sept. 1; copulation was begun promptly that evening and continued throughout all the next day. They separated for a few hours on the 3rd, but reunited that evening. On the 4th he was rejected, and on the 5th he was eaten; none could be found to take his place. On Sept. 10 the second egg-case was found. The insect lived an uneventful existence henceforth until its demise on Oct. 6.

Experiment 7. Aug. 18. The pair mated from noon until 3:30, and from 5 P. M. of Aug. 19 until noon of the 20th, and still a third time on the 21st, from 3 o'clock until night. For the four whole days following the pair was closely observed, but mating did not occur. On the morning of the 25th an egg-case was found, which evidently had been finished only a few hours previously. At 4 P. M. the male was devoured by the female. A new

one was promptly introduced but no mating occurred; the next evening he was found dead, but the death apparently had been a natural one. Aug. 27, 7 A. M. another was introduced, but he too was immediately devoured; his successor promptly met with the same fate at 4 P. M.—the third victim of this female's voracity. No more males could be secured until Sept. 1, when at 4 P. M. one was introduced only to be devoured in less than two hours. Two more were promptly added; by 9:30 one of these had mounted the female, but actual copulation had not begun. This condition continued until midnight of the 2nd, but at 6 the next morning the male was found dead. Twenty-four hours later a large, newly-made egg-case, the second for this female, was found and already she was again carrying the male, but without mating. This performance continued all day of the 4th and 5th, but the next morning revealed that this male also had been devoured. No more mates could be supplied, so the female lived alone until her death Sept. 10.

In addition to the foregoing complete experiments, the following fragmentary observations will contribute to our knowledge of this subject.

A male going through its last moult and becoming adult on Aug. 22, mated in the evening of the following day at the age of about thirty hours.

On one occasion an old male and three females were taken at random and placed in a cage. None of the females paid any attention whatever to him, so after six hours he was removed and an active young male which had voluntarily come to the cage was placed inside. In a short time one of the females mated with this one, while the other two assumed a furious attitude, erected their heads, curled their abdomens, raised their wings and occasionally leaped angrily at the pair. The couple was soon isolated to prevent any calamity. It is interesting that these three females all disregarded the first

male, and that immediately afterward all were extremely anxious, as their behavior clearly showed, to win favor of the second.

On Aug. 23, two males taken at random were placed with a gray female. They both fought for her possession; after half an hour one of them retired and the victor mated with her. Copulation continued until 5:30 the next morning. Within a half hour the pair had severed, and already both males were clinging to the female, one on each side, tightly clasping her prothorax with their spiny legs. Thus they persisted and contended until 4 P. M. when she fell from their grasp—dead—a victim of too ardent wooing.

On another similar occasion when a female was placed with five males, four of these were simultaneously clinging to her at the same time, the whole affair forming one struggling mass of life. Throughout even this she succeeded in maintaining her position, clinging to a twig.

A copulating pair fell from the ceiling of the laboratory upon the back of my neck. I brushed them hastily to the floor, and this caused their separation. The female ran swiftly away, pursued by the male, but even with the advantage of two feet of distance she was overtaken, mounted and in copulo in less time than it takes to tell.

On three occasions when two males were placed in one cage, they mounted one another, and spent from 3 to 6 hours in the normal attitude of mating, although no attempt was made to actually copulate.

In the accompanying photograph (Pl. IV) we have an attempt to show many individuals displaying various characteristic activities of the animal, in one group. In the background one can indistinctly see a pair in copulo; a gray female in the characteristic attitude of fight, the wings raised in a quarter circle like those of an angry goose, rests on the top of the twig, and a green female

is just beneath. In the lower part of the picture, a male can be seen about to mount the female. Note the greatly distended abdomen of the female which very soon will oviposit.

Pl. III shows two pairs which were chloroformed during mating while the male was being devoured from the head backward, as usual. This shows both the left and the right view of the connection.

The practice of the female devouring her mate may be one of the little economical devices of Nature. Since the male had already mated—done his duty, as it were—why continue a useless life? Why should he not go to help nourish the female while she goes through the function of egg-laying?

A female became adult on Aug. 16, was isolated and on Sept. 9 deposited an egg-case, but died three days later. Another which became adult on the same day and was likewise kept virgin, oviposited on Sept. 4 and died six days later. Both egg-cases appeared in all respects normal, but of course nothing emerged from them the next summer. This shows that females are capable of ovipositing and building the complex nest from their own bodies without the stimulus of fertilization, when about twenty days old.

It was thought that the males probably find the females by means of scent or other sense organs located in the antennae, as we have found in the cecropia moth,[15] but experiments on the removal of the antennae proved conclusively that this is not the case in the mantis.

Males with one or both antennae amputated, mounted and mated with the females just as quickly as did those with these organs intact.

It was also thought that the cerci of the female performed some function in mating, but the removal of these organs showed that they were of no value, for

[15] Trans. Acad. Sci. of St. Louis, 20: pp. 275-308.

matings occurred just as readily in the cerciless females as in the normal ones.

To briefly summarize, then, the points to be gleaned from these observations:

The males as well as the females are ready for mating very soon after becoming mature, *i. e.*, very soon after the last moult.

The species is highly polygamous and polyandrous and spend much time in mating. About six or eight hours is the usual duration of a single coitus, but it may be much less, or it may be extended to fifteen or eighteen hours.

As a rule, two egg-cases are deposited by each female, but mating is usually repeated in the few days' interval between the two.

The female generally refuses to mate during about three days preceding oviposition, and is at this time especially likely to rid herself of annoying suitors by eating them.

The male seeks out the female and will contend for her possession, the female will also fight for the male but no coquettish display or other antics of courtship such as have been recorded for other animals and insects, have been observed in either sex of this species.

The Making of the Egg-Case.

The making of the egg-case in the mantis is truly a wonderful phenomenon,—all the more so when compared with the process in other members of the family.

The eggs of most of the Orthoptera are deposited in capsules which may contain one or a great number of eggs.

In the cockroaches (Blattidae; see Sharp, 1895, p. 229 et. seq.) the eggs are laid in a horny capsule formed within the mother's body. This is carried about, protruding from the hinder part of the body, until it may be deposited in some suitable situation.

The eggs of the walking-stick (Phasmidae) are not systematically deposited but are discharged at random, remaining wherever they may chance to fall. The eggs resemble seeds and are dropped singly, each one enveloped in a capsule which is provided with a lid which is pushed off by the emerging insect.

In the locusts (Acrididae) we see the mode of oviposition differing widely from that of both the cockroach and the walking-stick. With her hard gonapophyses she excavates a hole in the ground wherein she deposits her eggs, together with a quantity of fluid. This hardens and protects the eggs, and hence in function corresponds to some of the capsules made by other insects of this group. It may have been from this primitive way of protecting the eggs that the present complex way of egg-case-making in our mantis evolved.

Some of the true locusts (Locustidae), katy-dids, etc., deposit their ova in twigs or stems of plants, arranging them in a very neat and compact manner, while others deposit their eggs in the earth.

The cricket (Gryllidae), which has a subterranean existence, deposits from two hundred to four hundred eggs. The mother watches over them very carefully until they hatch after three or four weeks; she then supplies the young with food until their first moult, after which they disperse.

For a good many years it was quite unknown just how our species makes its egg-case. It was thought by some naturalists that the eggs were deposited and the whole mass then covered by a substance which hardened over them, the whole process resembling the oviposition of the grasshopper. Others thought that the whole mass was formed inside the body of the mother mantis and then expelled entire, similar to the method of the Blattidae.

Sharp (loc. cit., p. 246) says: "The eggs of Mantidae are deposited in a very singular manner. The female

emits some foam like matter in which the eggs are contained. This substance dries and forms the oötheca; whilst attaining a sufficient consistency, it is maintained in position by the extremity of the body and the tips of the elytra, and it is shaped and fashioned by these parts."

One would take it from the above quotation that this account of egg-laying is for the entire family. If it be meant as Sharp states, an exception occurs in Stagmomantis carolina. Here the egg-case is fashioned only by the organs at the extremity of the body, and not in connection with the tips of the elytra; neither do the elytra or the tip of the body maintain the foamy substance in position until it hardens. The egg-case is built of the foamy substance, which holds its shape just as it is being fashioned, and no more needs the tip of the body to support it until it hardens than a clay model needs to be held by the modeler until it becomes firm. The insect leaves the pile immediately after finishing the gradual slope downward. The structure maintains its form alone, but sometimes the material is soft enough to be crushed between the fingers for perhaps six hours after its completion. In so far as the use of the elytra is concerned, either in fashioning or supporting the case during its construction, any of the illustrations in this paper will show that the wings cover less than two-thirds of the length of the body and cannot by any means touch the egg-case while it is being built.

A female and her egg-case just a few hours after oviposition are shown in Pl. IX. This picture is about exact size; the case was the largest ever met with in my experience with the mantis, while that shown in Pl. X is the smallest. Attention is called to the size and shape of the abodmen of this female just after oviposition (Pl. IX) in contrast with the usual distended condition prior to oviposition, as seen in the lower female on Pl. IV. One wonders how so large a mass could have been packed in that body.

When the architecture of an egg-case is studied, with its rows of cells, galleries and openings all arranged with precision, one realizes the complexity of the task of building such a structure and wonders where the insect could have acquired this knowledge, since of course it had no mother or experienced contemporaries to mimic in nest building, as have the higher animals or even the social insects.

The work of nest making consumes about two hours, and almost always is commenced at sunset, or after dark. Why this strange time of day should almost invariably be chosen has not been ascertained.

When about to begin ovipositing the mantis takes its position on the twig or surface, head downward, holding on by the two hind pair of legs; the front pair are held free as usual. The insect remains perfectly quiet, excepting for the contractions and expansions of the last two or three abdominal segments. Soon a small stream or ribbon of whitish substance issues from the body; this in appearance greatly resembles tooth-paste as it is pressed from the tube. A little later, when it is worked up and ready for the making of the egg-case it is foamy and mucilagenous, like the beaten white of egg, and has a delicate greenish tint. When the ribbon protrudes for about a quarter of an inch, it is pressed against the twig or surface by the tip of the abdomen, and adheres thereto. Let it here be stated that throughout the work the insect rests with the head downward and has never been seen to turn to observe the work while in progress. Furthermore, none of the appendages assist in the egg-case making, but the mass of material is pumped from the body by the movements of the last two or three abdominal segments only, and the whole is shaped by the ovipositor, the two small cerci probably aiding in the construction by acting as sense organs.

The last two segments, by a series of contortions, contractions and expansions, press out the ribbon of ma-

terial, which soon is converted into the frothy substance. After it has reached the proper consistency under the manipulation of the ovipositor, it passes on into the pile ready to be fashioned into the beginning of the egg-case. During this process the ovipositor is much distended and attains great size; the opening also is very large under this condition.

The egg-case is begun at the broad, rounded end, and the construction progresses from side to side; each row of cells across the case is completed and the partition re-enforced before the next tier is begun. The ovipositor slowly works into the soft substance until quite a hollow space is formed; this forms one row of four cells on one side; then it passes on to make the corresponding suite on the other side. The dividing line between the right and left sides of the egg-case is indicated by the braided appearance on top. Evidently the eggs[16] are deposited during this hollowing-out process, and are embedded in the soft substance. They undoubtedly leave the body with this material, but never in all of my mantis experience could they be seen even with the closest scrutiny. While burrowing into the substance at the sides the ovipositor goes in more deeply, evidently to shape the lateral galleries. After a suite on each side has been completed some of the substance from the periphery is stretched over it to form a re-enforced partition between this and the next row of cells; this is perfected and smoothed by left and right strokes of the ovipositor. The insect then repeats the process, hollowing out and partition making until the whole is completed. One tier of cells is always complete, even to the little ribbon-like flap on top which is the door, before the hollowing out of the next tier commences. If the egg-case be large, the mother mantis will sometimes move a short distance downward as the structure grows. How the openings are made at the top during the construction

[16] The eggs are from 2 to 2½ mm. in length.

could never be discerned, but the cerci constantly pass over the last addition much in the manner that the antennae of some insects are used. Whether these organs assist in making the openings, or whether they act only as sense organs and keep the whole affair symmetrical could not be ascertained. In one female the cerci were removed with fine scissors during the egg-case building. The structure was completed in a very irregular manner. This fact may, however, have been the result of the shock of cutting, since the same individual without the cerci a few days later made another egg-case of perfectly normal appearance. The eggs are not deposited in a haphazard manner, but all of them stand on end, one in each cell. They must of course be embedded in this manner, and perhaps the cerci come into use in some way in accomplishing this. The last abdominal segment carrying the cerci is constantly in one position throughout the work, apparently always keeping hold upon the last addition of the "braided" top. From the opening just beneath the last dorsal segment the material for the nest issues, while the work of molding the cells and shaping the mass is done by the characteristic ovipositor. This organ goes over and smoothes each partition two or three times, while the dorsal tip never looses its hold of the last braided addition.

An interesting fact is that immediately after ovipositing the insect walks away for a short distance and goes through the contortion of forming a circle of her body, and with her head partly inserted into the rear opening eats away all that remains of the nest material, and in so far as I have been able to see, quite relishes it. It may be that it is necessary to remove any of this substance before it hardens and would be a great hindrance to future copulation or oviposition, but this cannot be the sole reason, for I have seen insects of both sexes behave in the same manner on other occasions, and the females usually just after mating.

The insect after leaving the egg-case usually pays no more attention to it.

In order to ascertain the nature and condition of this substance which goes into the egg-case while still in the body of the female, a number of insects about to oviposit were preserved in chloral hydrate and dissected—that is, the chitin covering the entire abdomen was carefully stripped off. The illustrations (Pl. XIV, Figs. 1 and 2) show the dorsal and ventral surface of the rows of whitish ribbon, which are connected with the eggs that lie just beneath; it is this ribbon-like material worked into froth, that go into the construction of the egg-case.

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Ten egg cases of *S. carolina* brought forth 578 *S. carolina*, 240 *Podagrion* and 12 hyper-parasites, making a total fatality in *S. carolina* of 252 in 830.

1907. Girault, A. A.....Standards of the number of eggs laid by insects. Entomological News. XVIII. p. 89.
Number of eggs deposited.

1907. Rehn, J. A. G.....Records of Orthoptera from the vicinity of Brownsville, Texas. Entomological News. XVIII. p. 210.
One male at Brownsville, Texas, June, 1907.

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Popular juvenile account.

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*Those marked * not seen by the author.

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1908. Howard, L. O. and Chittenden, F. H.. The bag worm. Circular Bureau of Entomology U. S. Department of Agriculture. XCVII. p. 2. foot-note.
S. carolina gradually extending its northward range.

1908. Brimley, C. S..... Notes on the Orthoptera of Raleigh, North Carolina. Entomological News. XIX. p. 16.
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1909. Tucker, E. S..... Incidental captures of apterous and orthopterous insects at Plano, Texas. Entomological News. XX. p. 296.
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1910. Banks, N. ..... A list of works on North American entomology. Bulletin Bureau of Entomology U. S. Department of Agriculture. LXXXI. p. 93.

*1910. Smith, J. B..... Report on the insects of New Jersey. Report New Jersey State Museum. p. 175. f. 74.

1910. Rehn, J. A. G. and Hebard, M. ..... Preliminary studies of North Carolina Orthoptera. Proceedings Academy of Natural Sciences of Philadelphia. LXII. p. 621.
Virginia and South Carolina.

1911. Sherman, F. and Brimley, C. S..... Entomological News. XXII. p. 387.
Taken at Raleigh, Greensboro and Southern Pines, North Carolina.

*Those marked * not seen by the author.

EXPLANATION OF ILLUSTRATIONS.

Plate I.—A green female, showing the insect in act of moving head about. (Photograph from life.)

Plate II.—A male and female in copulo; showing the sexual diporphism of the species. (Photograph from life. Natural size.)

Plate III.—The male being devoured by the female while mating. (Natural size.)

Plate IV.—A group of adults. (Photograph from life.)

Plates V, VI, VIII.—Females and their natural environments. (Photograph from life. Natural size.)

Plate VII.—A dark gray and a green female in the attitude of fight. (Photograph from life.)

Plate IX.—A gray female and her egg-case. (Photograph from life.)

Plate X.—An abnormally small egg-case and its maker. (Photograph from life. Natural size.)

Plates XI, XII, XIII.—Nymphs in the fifth instar, showing the advantage of resemblance to environment. (Photograph from life. Slightly enlarged.)

Plate XIV.—A female with the integument removed, showing the ribbon-like substance, the material for egg-case making as it appears after hardening in chloral hydrate.—Fig. 1. Dorsal view.—Fig. 2. Ventral view. (Much enlarged.)

Plate XV.—Egg cases. (Slightly reduced.)

Plate XVI.—The structure of the egg-case.—Fig. 1. Horizontal section near botton (Floor).—Fig. 2. Horizontal section near top (Ceiling).—Figs. 3 and 4. Horizontal sections through the center.—Figs. 5 and 6. Longitudinal sections.—Figs. 7 and 8. Cross sections. (All enlarged.)

Plate XVII.—Nymphs just after emerging. (Greatly enlarged.)

Plate XVIII.—Fig. 1. Head, prothorax and forelegs of an adult female.—Fig. 2. A nymph going through its first moult. (Enlarged and ¾ natural size.)

Issued March 25, 1913.

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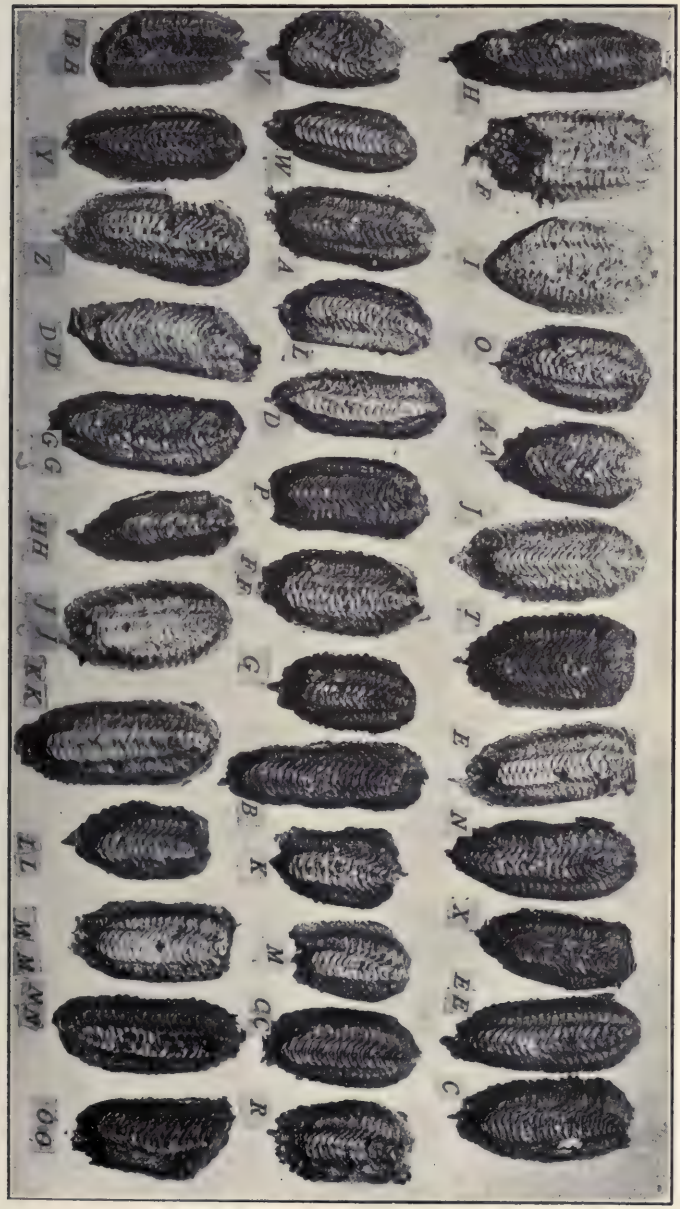

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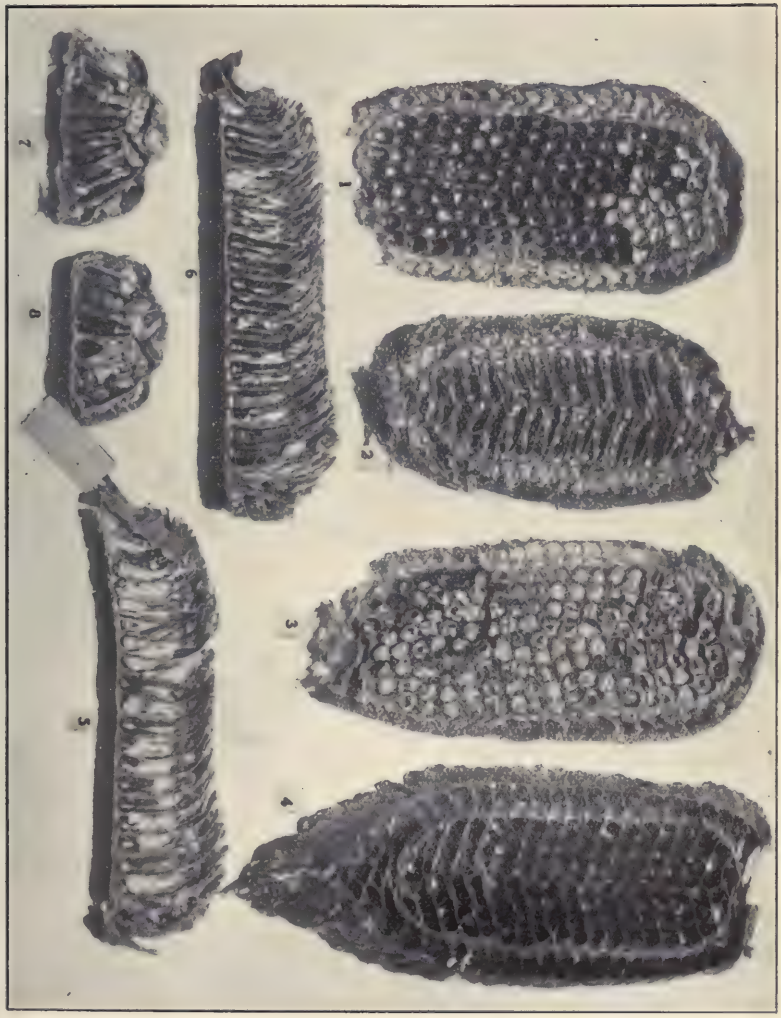

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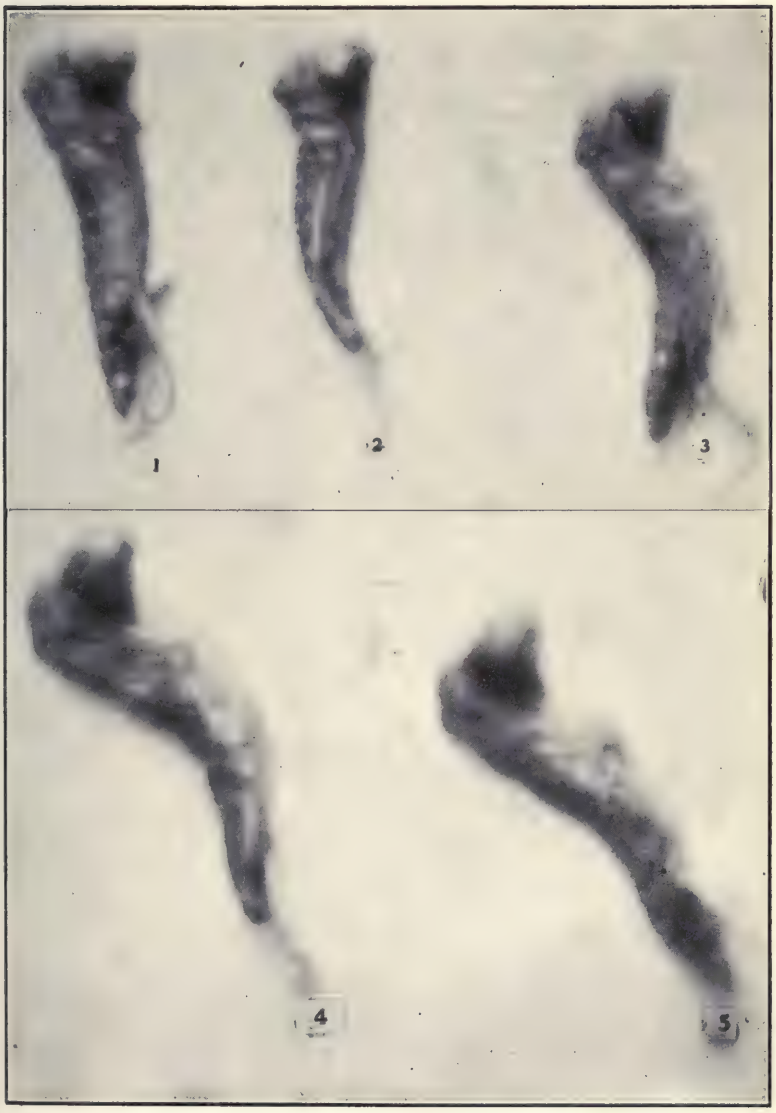

STAGMOMANTIS CAROLINA.

STAGMOMANTIS CAROLINA.

LOCAL MAGNETIC STORMS.*

FRANCIS E. NIPHER.

The work of the Ampère nearly a century ago, taken in connection with the fact that fragments of a steel magnet are also magnets, was sufficient grounds for the theory that the molecules of magnetic matter may contain closed electric currents. The discovery of the electron gave additional weight to the older suggestion. With a view of obtaining direct evidence of this condition within a steel magnet, the writer began a series of experiments which have led to interesting results, but which leave the original question unanswered.

It appeared possible that the magnetic force of a steel magnet might be varied by draining negative electrons from it. This was done by connecting it with the positive terminal of an influence machine.

The magnet to be tested was 30 cm. in length and about 2.5 cm. in diameter. It was composed of a thin film of steel 0.2 mm. in thickness. It was formed of a single layer of steel wire wound longitudinally on a piece of rubber hose, rendered rigid by means of a core of wood. The winding was in the form given the copper windings of a drum armature. The wire was held in place by silk cord, and the steel wire crossing the ends of the hose was removed. The wire was then magnetized.

This wire magnet was used as a deflecting magnet, being placed at right angles to a needle suspended on a silk fiber. The needle was wholly enclosed in a metal shield. A mirror attached to the suspension was observed through a glass window covered with copper wire gauze. A telescope and scale was used in observing deflections, one mm. having an angular value of 3′.4. The deflecting effect of the wire magnet was balanced by a

*Presented March 3, 1913.

large bar magnet placed on the opposite side of the needle. The needle was rendered sensitive to changes in the turning moment of the wire magnet, by partially compensating the effect of the earth's field by means of bar magnets on either side of the needle. The time of a complete vibration in the earth's field within the building was the same, when all magnets were removed as when the opposing deflection magnets were in place, namely, 8.94 seconds. The compensating magnets increased the vibration period to 20 seconds.

It was found when either terminal of the influence machine in an adjoining room was connected with the insulated wire magnet, the other terminal being grounded, that the deflecting effect of this magnet was increased. The angle of deviation could not be determined with any precision, on account of fluctuations in the needle, but it amounted to about 15 minutes of arc. In some of the earlier experiments the reverse result was obtained. It was then concluded that the attraction between magnets, like that between masses of matter, depends upon their electrical potential. This question is, however, still an open one. It was found when the air around the magnet is rendered as quiet as possible, and when no disruptive effects are permitted along the conductor, that the magnet becomes apparently stronger. It was also found that disturbances of the air around the magnet appeared to diminish its deflection effect. It was found when the charged magnet was covered with tinfoil, that the change in the defection due to electrification was apparently unchanged. It was found when the air around the magnet was disturbed by the movement of an assistant, or by means of a palm-leaf fan, that its deflecting effect due to electrification was diminished. When the fan was operated during alternate semi-vibrations of the needle, the oscillations of the needle could be gradually increased in amplitude to five or six degrees of arc.

All of this evidence indicates conclusively, that the apparent increase in the strength of the deflecting magnet when in contact with the terminal of the machine, is due to an increase in the permeability of the air around the magnet.

The "charged" molecules of air appear to behave like iron filings, in that they set in the field of the deflecting magnet with the planes of the electrical whirls at right angles to the lines of force. It was found that a solid steel magnet gives similar results.*

The electrified magnet was placed in a glass tube having an internal diameter of about 4 cm. The tube extended to the metal shield enclosing the needle. This metal shield was grounded. It was then found that the deflecting effect of the magnet was less, than when the magnet was not connected with the influence machine. When the machine is stopped, the deflection at once becomes greater than normal, but it quickly diminishes to normal value. The reason for this was explained, by filling the tube with tobacco smoke before the machine was started. The column of air within the tube was in continual commotion while the machine was in operation. The molecules of ionized air could not then set in orderly array along the lines of force. It is remarkable that under such conditions, the permeability of the air-column is less, than when the magnet is not in communication with the machine.

When the insulated magnet was enclosed in a mass of cotton batting, having a diameter of about 50 cm.,

*A bar magnet thus used as a deflecting magnet, over which a sheet of glass is placed, extending to the shield around the needle, gives most interesting results when the plate is sprinkled with iron filings. The increase in permeability due to tapping the plate is plainly evident. When the filings are gathered in a heap at the equator of the magnet, its deflecting effect is greatly diminished. If at any point in the field of this magnet, the iron filings are disturbed by means of a brush, the magnetic field will be disturbed throughout. If the iron filings were free to move, they would respond to the disturbance. The suspended needle does respond.

electrification of the magnet had no appreciable effect upon its deflecting effect. The fibers of cotton then appear to determine the lines along which the ionized air-filaments shall form.

While observing the needle during a wind storm in which sudden and violent gusts of wind occurred, it was observed that the vibrations were affected in a marked way at the beginning of a wind-gust. The velocity of the needle would be suddenly and greatly changed. Several times it was observed that when it had come to rest at the extreme of a vibration, it would suddenly start into motion and in the direction in which it had been moving. Sometimes the velocity of swing would be greatly diminished, the motion would be arrested prematurely, and in the return swing, the velocity would be increased to a marked degree. These sudden changes in the motion of the needle occurred at the beginning of a gust of wind of unusual severity. In one case the unusual velocity of the wind persisted apparently unchanged for a couple of minutes, but the change in the motion of the needle occurred at the beginning of the gust. The amplitude of successive semi-vibrations would sometimes change from five minutes to half a degree, or the reverse. The amplitude was sometimes observed to gradually increase from zero to a maximum and then diminish again to zero. The maximum amplitudes were greatest when the wind was most violent and when it came in sudden gusts. On days when the wind was mild the maximum amplitude would not exceed one degree. On days of violent winds the amplitude has often risen to eight degrees. Notwithstanding the fact that the gusts of wind occur at irregular intervals, the variations in the amplitude of the needle resemble an irregular series of beats, as will be seen by reference to Plates XIX and XX.

The observations represented in these two plates were made on consecutive days, when the wind was unusually

violent. In Plate XIX the general direction of the wind was at right angles to the needle. On the next day the wind had shifted about 90°, and its direction was parallel to that of the needle. The compensating adjustments of the needle were the same in both cases, and the wind was no more violent on the second day than on the first. Plate XX.

The vertical lines represent the amplitude of oscillation in scale divisons. The lower end represents the scale reading to the left of the zero, and the upper end of each line represents the scale reading to the right. The observations of Plate XIX covered an interval of 1 h. 37 m. 38 s., during which time 290 to and fro oscillations occurred. The scale divisions were in millimeters, each having an angular value of 3.4 minutes of arc. The middle line represents the mean of the extreme readings of the scale. In Plate XX one hundred consecutive oscillations are represented.

The needle was made of tool steel having a diameter of $\frac{1}{8}$ inch and a length of 3.5 inches. It was mounted in a wire clutch, and with it was placed a brass rod of about the same dimensions. This arrangement was adopted in order to tone down some of the irregularities shown in the vibrations of a highly magnetized needle made of a single small wire of steel, such as knitting wire.

The needle with small moment of inertia follows the variations in the earth's field more closely, but summation effects are occasionally obtained with the needle of larger moment, and the amplitude of vibration is thereby greatly increased.

These results are in all cases obtained when the earth's field is partly compensated, so that the changes are a large fraction of the resultant directive force.

It is of course understood that these observations do not indicate any change in the intensity of the earth's magnetic field, due to linear transfer of ionized air as

in the Rowland effect. They indicate a swaying of the lines of force, due to variations in permeability. They indicate that ionized molecules of air in the earth's magnetic field tend to set in definite position with respect to the lines of force. This would cause local variations in the position of the magnetic needle, and local and rapidly varying changes in intensity of the field. The local electrical condition of the air at the station of observation and at the moment when the wind-gust occurs is also involved.

Some visible evidence of auroral streamers have been obtained around the poles of a steel magnet. Satisfactory photographic evidence has not yet been obtained on account of the flickering character of the phenomena, and the inductive effects of the walls of the bell-jar in which the magnet is hung.

Plans are being made to repeat some of the work described in this paper, at the summer home of the writer, at the north end of Lake Huron, where the surroundings are those of Nature.

These observations were made in Eads Hall, a two-story building with granite walls, and floors of reinforced concrete. No vibrations of the building due to wind could have had any effect upon the observations. The only disturbances which complicated the results were those due to electric cars, and railway trains. Their effect was observed when that of the wind was inappreciable, and no effects comparable with those shown in Plates XIX and XX have ever been observed.

The tracks of these railways were about 650 feet distant.

Reversal of the Rowland Effect.

In a former paper in these Transactions, No. 3. Vol. XXI, this subject was discussed. The results there described have been obtained by suspending the wire shown in Fig. 1, p. 81, on three or four long silk fibers. The wire was placed in contact with vertical strips of hard

rubber, against which the wire was lightly pressed by small flexible bundles of hair. The wire is then slightly lifted when longitudinally displaced.

The discharge terminals were in the form of rings which encircled the wire near its ends, the ends being bent downwards outside of the ring terminals.

The air in the room must be very quiet, in order to prevent its effect upon the suspending fibers of silk. Such circulation as exists in a room heated by warm air interferes with the result. If the wire is placed in a tube as in Fig. 1 referred to above, the tube may be divided in half, and a pointer consisting of a fine fiber of glass, or a silk fiber, may be attached to the wire between the tubes. This serves as a mark upon which the telescope may be set, for observing the displacement. The support for the glass tubes must of course be provided with leveling screws.

EXPLANATIONS OF THE PLATES.

Plate XIX represents the amplitude and extreme scale readings of a magnetic needle during a wind storm, the effect of the earth's field being partly compensated by bar magnets. The resultant field was about 1/5 of H. The general direction of the wind was at right angles to that of the needle.

Plate XX, conditions as in Plate XIX, excepting that the wind direction was parallel to that of the needle. The effect on the needle is ascribed to wind-gusts which locally varied the permeability of the air, at fairly regular intervals.

Issued April 5, 1913.

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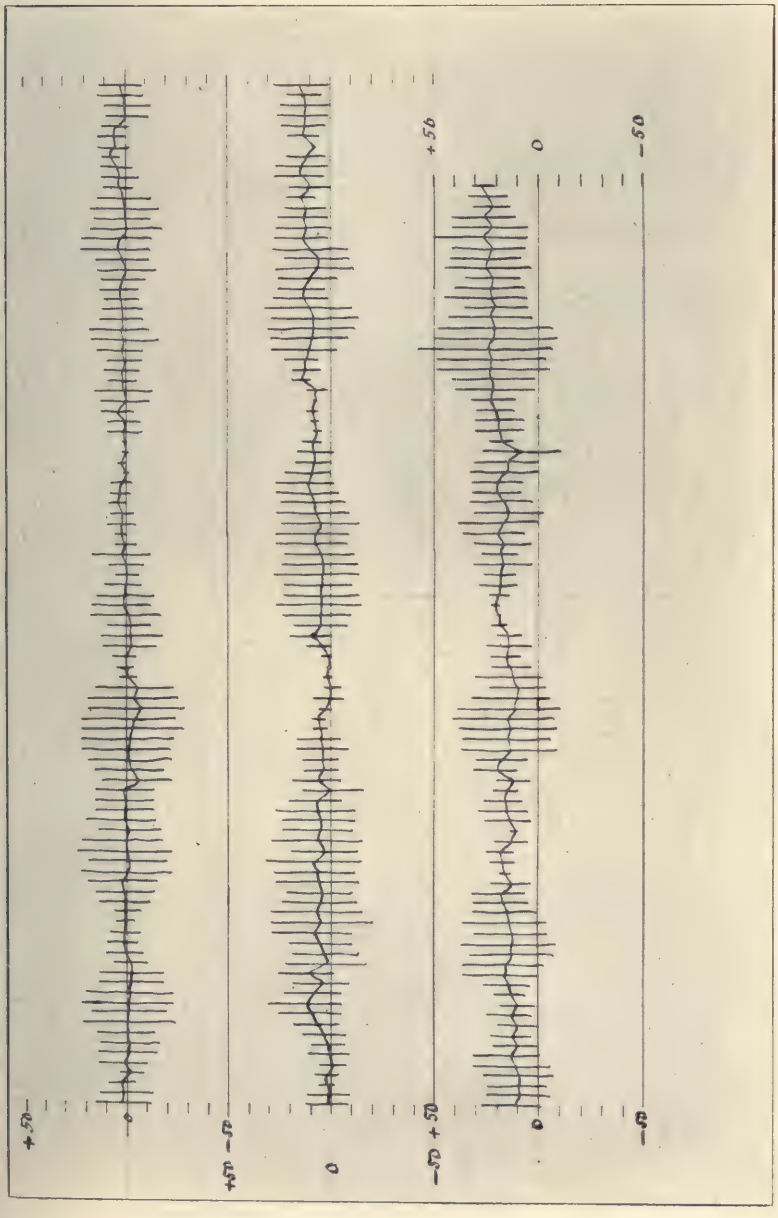

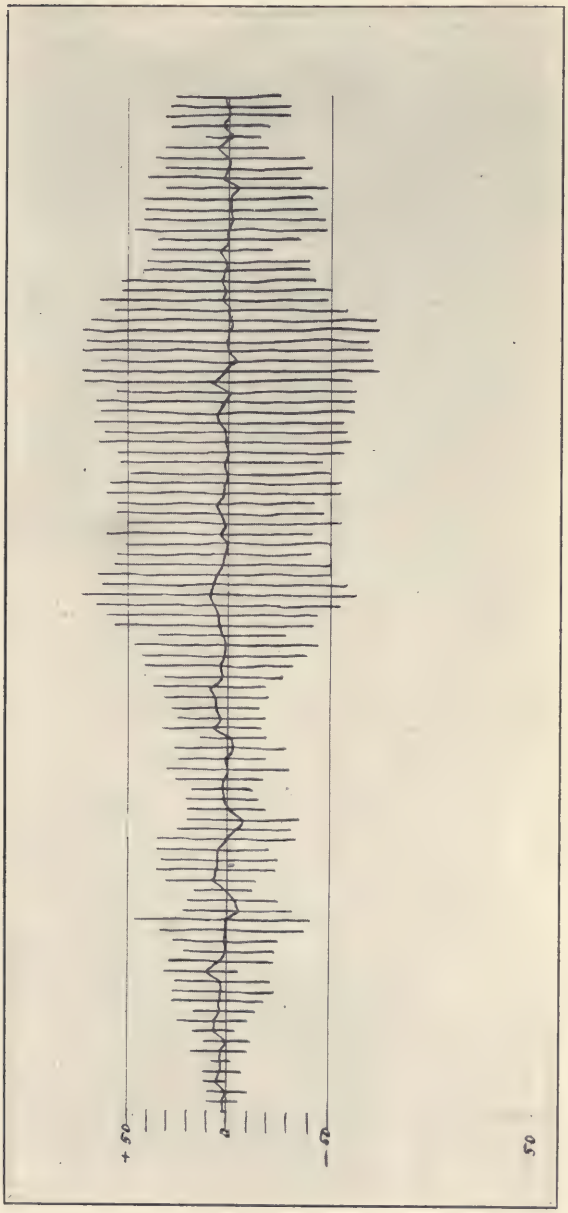
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A PRELIMINARY LIST OF THE MOLLUSCA OF MISSOURI (EXCLUSIVE OF THE UNIONIDÆ.)*

F. A. Sampson.

To this time no list of the shells of Missouri has been published. In many of the other States much more work has been done than in this. Baker's Catalog of the Mollusca of Illinois showed that ten counties in that State had been carefully listed, and records had from fifty-nine other counties. Lists of species had been published as early as 1854.

Five writers had published papers on the shells of Michigan, when in 1905 Bryant Walker gave a list of 272 species in that State. Of quite a number of other States lists have been published. In Missouri the author published a report on the shells of Pettis county, in the Kansas City Review of Science and Industry, and later in the Bulletin of the Sedalia Natural History Society, and published notes on some of the other counties of the State. Pilsbry and Ferriss collected in some of the southern counties of the State, but as a whole little has been done. The author interested Mr. O. A. Crandall, of Sedalia, a few years before his death, and he had collected in a number of the counties; his collection is now a part of the Bryant Walker collection in Detroit. The collecting of the author has been done in a hurry at odd hours while doing other work; and while extending into sixty-four counties, has approached thoroughness in but one. It is to be hoped that this paper will be the means of inducing a number of other persons to collect in their home localities, and communicate the results to the writer, that a more complete list

*Presented by title to The Academy of Science of St. Louis, June 2, 1913.

may be made. The present list contains 61 species and 12 varieties of land shells, and 46 species and 4 varieties of water shells.

Acknowledgments are due to Messrs. Bryant Walker, A. C. Billups, V. Sterki, F. C. Baker and B. Shimek for the identification of shells submitted to them.

Binney in his Manual of American Land Shells divides the United States into three provinces—the Pacific, Central and Eastern. The latter includes all of North America north of Mexico and east of the Rocky Mountains. It is divided into three regions, the Northern, Interior and Southern; Missouri is in the Interior Region. The Ozarkian fauna belongs to it, and is found in the Ozark Mountain regions of Missouri and south and west. This fauna contains some species which are peculiar to it, and others which have been derived from the Cumberland subregion, although the low lands between do not contain them; other species have come from the Texas subregion. That part of the Ozark region which is in Missouri does not have any species that is peculiar to that part of it. The State north of the Ozark region has, of course, many species that are found widely scattered in the Interior Region.

There have not been many new species and varieties described from Missouri. The following is the list:

Bulinus distortus Hald, St. Louis.
Bythinella aldrichi Call, Reynolds county.
Goniobasis potosiensis Lea, Potosi.
Goniobasis ozarkensis Call, Shannon county.
Lymnaea columella var. a Say, Cold Water creek.
Physa crandalli Baker, Pettis county.
Planorbis sampsoni Ancey, Pettis county.

The following list of species gives the counties in which the author has collected each, and shows in parenthesis the number of specimens from each locality in the collection of the author, it being in many cases the total number found. Reference is also made to reports of

other localities given by other authors. A total of 117 species and varieties is given, and a record of 900 localities.

Systematic Catalogue of Species.

Pelecypoda.

TELEODESMACEA.

Cyrenacea.

Sphæriidæ.

sphærium Scopoli.

1. Sphærium solidulum Prime.

   Jackson, Cape Girardeau Co.; Stream, Peirce City, Lawrence Co.; Lamar, Barton Co. (Resembles.)

2. Sphærium stamineum Conr.

   Marmaton River, Nevada, Vernon Co.

3. Sphærium stamineum forbesi Baker.

   McAllister Springs, Saline Co.; Flat Creek and Springfork, Pettis Co.

4. Sphærium striatinum Lam.

   Flat Creek and Springfork, Pettis Co.; Lamar, Barton Co.; Marmaton River, Nevada, Vernon Co.; McAllister Springs, Saline Co. (near); Sarcoxie, Jasper Co.; Dent Co.

musculium Link.

5. Musculium transversum Say.

   Lamar, Barton Co.; North River, Palmyra, Marion Co.; Jackson, Cape Girardeau Co.; Coon Creek, Jasper Co.; Flat Creek and Springfork, Pettis Co.

6. Musculium truncatum Lindsey.

Pond, Flat Creek, Pettis Co.

7. Musculium securis Prime.

Flat Creek, Pettis Co. (or near).

8. Musculium elevatum Hald.

Coon Creek, Jasper Co.; Jackson, Cape Girardeau Co.; Pond, Flat Creek, Pettis Co.

pisidium Pfeifer.

9. Pisidium compressum Prime.

Flat Creek, Pettis Co.

10. Pisidium frandulentum Sterki.

Flat Creek, Pettis Co.

11. Pisidium noveborensis Prime.

Flat Creek, Pettis Co. (near).

12. Pisidium neglectum Sterki.

Branch of Muddy Creek, Pettis Co.

GASTROPODA.

Anisopleura.

PROSOBRANCHIATA.

Rhipidoglossa.

Helicinidæ.

helicina Lam.

13. Helicina orbiculata Say.

Stone Co. (Pilsbry); Marble Cave, Stone Co. (Stearnes).

Shimek says this is not found north of the south line of Kentucky, either recent or fossil.

14. HELICINA ORBICULATA TROPICA 'Jan.'

Jasper Co. (2); Barry Co. (9); Macdonald Co. (5); Seligman, Barry Co. (Pilsbry); Chadwick, Christian Co. (Pilsbry & Ferriss).

Postpliocene:—Providence, Boone Co. (8).

15. HELICINA OCCULTA Say.

Postpliocene:—Glasgow, Howard Co. (8); St. Joseph, Buchanan Co. (6); Kansas City, Jackson Co. (Shimek); Boonville, Cooper Co. (Shimek); St. Louis (Shimek).

Living specimens have been found in Iowa and some other States, but none have yet been recorded from this State.

TÆNIOGLOSSA.

VIVIPARIDÆ.

VIVIPARA Lam.

16. VIVIPARA CONTECTOIDES W. G. Binney.

Binney in Part III of Land and Fresh Water Shells of North America says that this has been found in Missouri.

17. VIVIPARA INTERTEXTA Say.

Henry Co. (4).

CAMPELOMA Rafinesque.

18. CAMPELOMA SUBSOLIDUM Anth.

Petite Saline, Cooper Co. (4); Flat Creek, Pettis Co. (8), (1); Stomach of wild duck, Pettis Co. (14); Marmaton River, Nevada, Vernon Co. (3); Cow Skin River, Macdonald Co. (6); Grand Falls, Jasper Co. (1); Pond, Current River, Van Buren, Carter Co. (7); Black River, Poplar Bluffs, Butler Co. (5);

Big River, St. François Co. (1); Little River, Mo. (Call.); Dent Co. (15); Mississippi River, Pike Co. (5).

The collection has two reversed specimens from Pettis county.

19. Campeloma integra Say.

In his description of this species Say states that it inhabits the waters of the Missouri, but does not give any locality. However, according to Call it is not found in Missouri.

Amnicolidæ.

bythinella Moq-Tand.

20. Bythinella aldrichi Call.

Branch of Black River, Reynolds Co. (8).

These specimens were received from R. Ellsworth Call, and were a part of the original type lot. The species was described in the Bulletin of the Washburn College Laboratory of Natural History, December, 1886.

amnicola Gld. & Hald.

21. Amnicola parva Lea.

Flat Creek, Pettis Co. (175); Lamar, Barton Co. (1); Hinkston Creek, Columbia, Boone Co. (3).

22. Amnicola cincinnatiensis Lea.

Osage River, Cape Galena, Morgan Co. (1); Flat Creek, Pettis Co. (75); Jasper Co. (17), (13); Grand Falls, Jasper Co. (1); Marmaton River, Nevada, Vernon Co. (25); Gravois Mills, Morgan Co. (8); Lamar, Barton Co. (25); Peirce City, Lawrence Co. (angulate var.) (8); Lost Creek, Seneca, Newton Co. (angulate var.) (1).

23. AMNICOLA LAPIDARIA Say.

Postpliocene:—Near St. Louis (Hambach).

POMATIOPSIS Tryon.

24. POMATIOPSIS LAPIDARIA Say.

Camden Co. (1).

In the collection of the Smithsonian Institution are specimens from St. Louis, with a query as to whether they were postpliocene. In Part II of the Land and Fresh Water Shells Binney states that the species is found from Missouri to Michigan.

PLEUROCERIDÆ.

PLEUROCERA Rafinesque.

25. PLEUROCERA ELEVATUM Say.

Flat Creek, Barry Co. (6); Current River, Van Buren, Carter Co. (9); Black River, Poplar Bluffs, Butler Co. (13), South Missouri, (18); Center Creek, Sarcoxie, Jasper Co. (15).

26. PLEUROCERA ELEVATUM LEWISII Say.

Spring, Howell Co. (10).

27. PLEUROCERA SUBULARE Lea.

Niangua River, Hahatonka, Camden Co. (2); James River, Galena, Stone Co. (2); Callaway Co. (Greger).

GONIOBASIS Lea.

28. GONIOBASIS PLEBEIUS Anth.

Osage River, Cape Galena, Morgan Co. (12); Coffin Spring Branch, Morgan Co. (26); Gravois Creek, Morgan Co. (37); Branch Indian Creek, Morgan Co. (30); Mineral Branch, Mor-

gan Co. (16); Niangua River, Hahatonka, Camden Co. (15); Possum Creek, Camden Co. (21); Springfork, Camden Co. (52); Prairie Hollow Creek, Coellida, Camden Co. (13); Flat Creek, Pettis Co. (14); Shoal Creek, Barry Co. (15); Flat Creek, Barry Co. (6); Roaring River, Barry Co. (striped) (8); Same (light color) (9); Thatcher Branch, Benton Co. (14); Current River, Van Buren, Carter Co. (20); Mc—— Spring, Howell Co. (12); Teague Creek, Webster Co. (10); James River, Galena, Stone Co. (5); North Fork Soc River, Greene Co. (17); South Fork Soc River, Greene Co. (20); Center Creek, Sarcoxie, Lawrence Co. (13); Spring River, Verona, Lawrence Co. (20); Spring River, Carthage, Jasper Co. (20); Branch, Carthage, Jasper Co. (8); Lost Creek, Seneca, Newton Co. (17); Shoal Creek, Newton Co. (16); Cow Skin River, Macdonald Co. (18); Butler Creek, Noel, Macdonald Co. (9).

The genus Goniobasis is more widely distributed than the Pleurocera, and more species of it have been described than of the latter. As early as 1873 nearly five hundred species of Strepomatidæ had been described, they being exceedingly abundant in Tennessee and adjoining territory. At that time Tryon stated that the Mississippi river from its junction with the Ohio to its mouth seemed to have formed an insurmountable barrier to the dispersion of these shells. However in the same work he gave the types of one species from Potosi, Missouri, and of another from Saline county, Arkansas. This latter probably, under the name *sordida* was the one that he stated was found on both sides of the Mississippi. I cannot agree, however, that *plebeius* is a synonym of *sordida,* in which the whorls are convex, while in *plebeius* they are smooth and flattened, and the angle around the body whorl is generally present. These are also characteristics of *cubicoides,* a species described

from Indiana; one that was more likely to have extended to the west side of the Mississippi, than was one from Tennessee, the locality of *sordida.* But if the two names *plebeius* and *cubicoides* represent the same shell, the former has precedence in time of ten years, and consequently the latter is a synonym of the former.

There are noticeable differences in the Goniobases from different counties of Missouri, and if every minute difference made another species the list of names would perhaps not be small, but until this genus has been worked over thoroughly it is better to err in having too few names instead of too many.

Years ago some of the above shells were submitted to Mr. Tryon, and his decision was that they were *saffordi,* and that *cubicoides* and *plebeius* were both synonyms of *saffordi.*

29. Goniobasis livescens Menke.

Branch of Fox Creek, Douglas Co. (13); Branch of Gravois, Morgan Co. (10); Branch of Gravois below Mineral, Morgan Co. (14); Speer's Spring, Morgan Co. (25); Huff's Branch of Gravois, Morgan Co. (15); Mill Race, Gravois Mills, Morgan Co. (11); Clear Creek, Peirce City, Lawrence Co. (22); Jacks Falls, Current River, Carter Co. (Billups).

30. Goniobasis ozarkensis Call.

Blue Spring, Shannon Co. (4).

These specimens were received from R. Ellsworth Call, and were a part of the original type lot. The species was described in the same publication as *Bythinella aldrichi.*

31. Goniobasis depygis Say.

Jacks Falls, Current River, Carter Co. (Billups); Mississippi River, St. Louis (Billups); Spring Valley Creek, Shannon Co. (Billups).

32. Goniobasis potosiensis Lea.

King River, Potosi, Washington Co.; Carter Co. (Billups).

The type specimens of this species were from Potosi.

33. Goniobasis sordida Lea.

R. Ellsworth Call in Bulletin of Washburn College Laboratory gave a list of four species of Goniobasis found west of the Mississippi, and east of the Rocky Mountains, three of which were stated to be from Missouri, the above being one. He did not give the exact locality. See as to this also under *plebeius*.

34. Goniobasis cubicoides Anth.

This was one of the four species given by Call as found west of the Mississippi, but his specimens were no doubt what this report gives as *plebeius*.

Euthyneura.

PULMONATA.

BASOMMATOPHORA.

Hydrophila.

Physidæ.

physa Drap.

35. Physa anatina Lea.

Pond, Springfork, Pettis Co. (33); Nevada, Vernon Co. (5).

The Nevada specimens were thought by Pilsbry to be a "curious form of *albofilata*."

36. Physa gyrina Say.

From Pettis County:—Branch Flat Creek, May, 1883, (6); Pond, Flat Creek, May, 1883, (5); Sampson farm pond, Nov., 1883, (9); Same

place, Sept., 1885, (9); Stream, Gentry's, July, 1885, (12); Stream, n. w. Gentry's, May, 1885, (18); Walnut Creek, Oct. 1892, (33); Little Muddy Creek (49); Sedalia, Hildebrand pond (12); Crawford branch, Spring Fork (12); Small stream, Yankee's (24); Branch, Pin Hook bridge (15); Brown Spring Lake (9); East line of Co. (9); Pond, Spring fork Creek (3); Small pond, Flat Creek (4); Muddy Creek, Pin Hook bridge (15).

From Morgan County, Oct., 1891:—Porter Spring (15), (18); Branch, 4 miles from Versailles (3); Branch, Moreau (13); Mineral branch (9); Cave Spring (10).

From Barry County, Aug., 1891:—Shoal Creek (1); Mineral Spring (30); Roaring River Spring, July, 1891, (13); Same, June, 1891, (11); Spring near Roaring River Spring (12); Flat Creek, Cassville (27).

From Douglas County:—Spring on mountain (7); Spring, Livingston's (15); Branch Fox Creek (19); Clifty Creek (13); Branch (11).

From Camden County, Oct., 1891:—Wheeler's Spring (7); Camp Branch (17); Small Branch (13); Springfork Creek (11); Wainwright branch (4); Hahatonka Lake (15).

From Jasper County:—Shoal Creek, below Grand Falls (2); Spring, Sherwood (10); Coon Creek (10); Pond, Carthage (11).

Branch of Teague Creek, Webster Co. (20); Lost Creek, Seneca, Newton Co. (9); Butler Creek, Noel, Macdonald Co. (3); Moreau Creek, Moniteau Co. (9); Swamp, Scott Co. (14); La-

mar, Barton Co. (18); Pond, Nevada, Vernon Co. (7); Pond, Springfield, Greene Co. (13); Pond, Current River, Van Buren, Carter Co. (14); Greenfield, Dade Co. (6); New Madrid, New Madrid Co. (1); Black River, Poplar Bluff, Butler Co. (2); Branch St. François Co. (10); Big River, St. François Co. (5); Branch, Jackson, Cape Girardeau Co. (12); Stream, Aurora, Lawrence Co. (27); Godby's, Cooper Co. (10); Stone Co. (Stearns). Pond, Fern Glen, St. Louis Co. (10); Spring branch, Potosi, Washington Co. (32); Blees Academy lake, Macon, Macon Co. (18); Small branch, Chillicothe, Livingston Co. (23); Branch of Salt River, Paris, Marion Co. (23); Spring branch, Ironton, Iron Co. (20); Pond, Allanville, Cape Girardeau Co. (10); Spring branch, Ste. Genevieve, Ste. Genevieve Co. (45); Stream, Jackson, Cape Girardeau Co. (11); Pond, Rivermines, St. François Co. (20); Spring branch, Hannibal, Marion Co. (35); Callaway Co. (Greger); Dent Co. (15); Hinkston Creek, Boone Co. (12).

Postpliocene:—Below Platte river (Hambach).

Mr. O. A. Crandall, of the Missouri Trust Company of Sedalia, Missouri, on becoming a member of the American Conchological Society, in accordance with the plans of that society, adopted a specialty—the very difficult one of the American Physæ. He gave much investigation and study to the subject, and in July, 1901, he commenced the publication in the Nautilus of the results of his studies, during the publication of which he suddenly died. He examined and labelled all the Physæ that were then in my collection, and the present list is made in accordance with his determinations. Before that time I had supposed that some of the lots were *heterostropha,* but Mr. Crandall did not so identify any lot from Mis-

souri. His decision was that he had never seen any *heterostropha* from west of the Mississippi river.

37. Physa gyrina albofilata Ancey.

Cow Skin river, Macdonald Co., Aug., 1891, (8), (17); Nevada, Vernon Co.; Chadwick, Christian Co. (Pilsbry & Ferriss).

Some years ago I sent some Physa from Eureka Springs, Arkansas, to the late Mr. Ancey, then of France, and later of Algeria; these he described as *albofilata*. The same beautiful shells have been found in Missouri as above.

38. Physa oleacea Tryon.

Branch Cedar Creek, Pettis Co., Oct., 1883, (10); Pond, west of Gentry's, Pettis Co., May, 1885, (24); Pond, northwest of Gentry's, July, 1885, (14); Stream, Boonville, Cooper Co. (10); Pond on Gentry farm, Pettis Co. (15).

39. Physa integra Hald.

From Pettis County:—Flat Creek, Aug., 1886, (17); Same, Sept., 1886, (3); Muddy Creek, Aug., 1886, (14); Flat Creek, Aug., 1881, (40); Pond, Freight depot, Sedalia, Sept., 1884, (11); Same place, July, 1885, (15); Dresden, Sept., 1885, (15); Muddy Creek, Pin Hook, Apr., 1891, (15).

Hannibal, Marion Co., Sept., 1885, (15); Palmyra, Marion Co., Sept., 1887, (16); Kansas City, Jackson Co. (17); Bear Creek, Marion Co. (25); Lake, Peirce City, Lawrence Co., 1880, (29); Same, April, 1884, (20); Spring, Nevada, Vernon Co., Aug., 1884, (25); Pond, Nevada, Aug., 1884, (14); Branch, Columbia, Boone Co., April, 1903, (26); Same, May, 1903, (16).

40. PHYSA INTEGRA HALEI Lea.

Small stream, Peirce City, Lawrence Co., Sept., 1887, (7).

So identified by Pilsbry.

41. PHYSA GROVENORI Lea.

From Pettis County:—Crandall's fountain, Sedalia (20); Slough, Flat Creek, July, 1883, (16); Pond, E. Brown's, Sept., 1884, (10); Branch, Springfork (50); Pond, Georgetown, June, 1885, (35); McNutt's Branch, Pin Hook, April, 1891, (15); Springfork, Aug., 1881, (35). Lake, Peirce City, Lawrence Co., June, 1881, (35); Lake, Mountain Grove, Wright Co. (4); Pool, Cow Skin River, Macdonald Co., July, 1891, (3); Nevada, Vernon Co., Aug., 1884, (30); Williamsville, Wayne Co., 1889, (14); Blue Lick Springs, Saline Co., 1892, (34).

42. PHYSA CRANDELLI Baker

Clear and Muddy Creeks, Pettis Co.

This was described by Mr. Crandall as *Physa rhomboidea,* but as that name was preoccupied, it was changed as above by Mr. Baker.

43. PHYSA PLICATA DeKay.

Near Mouth of Wolf River (Hambach).

44. PHYSA ELONGATA Say.

Mouth of Platte River (Hambach).

ANCYLIDÆ.

ANCYLUS Geoffroy.

45. ANCYLUS KIRKLANDI Walker.

Muddy Creek, Pettis Co., 1886, (8); Flat Creek, Pettis Co. (16); Same, Aug., 1886, (25); Osage

River, Cape Galena, Morgan Co. (12); Peirce City, Lawrence Co. (10); Center Creek, Sarcoxie, Jasper Co. (7); Grand Falls, Jasper Co. (2); Cow Skin River, Macdonald Co. (2).

46. Ancylus rivularis Say.

Jasper Co. (8); Peirce City, Lawrence Co. (3).

Planorbinæ.

planorbis Müller.

47. Planorbis bicarinatus Say.

Flat Creek, Pettis Co. (25); Pond, Flat Creek (12); Crandall's fountain, Sedalia, Pettis Co. (13); Cooper Co. (3); Lamar, Barton Co. (1); Lake, Mountain Grove, Wright Co. (2); Spring branch, Hannibal, Marion Co. (23); Callaway Co. (Greger); Blees Academy lake, Macon, Macon Co. (13).

48. Planorbis trivolvis Say.

Flat Creek, Pettis Co. (15); Pond, Pettis Co. (6); Pond, E. Brown's, Pettis Co. (7); Pin Hook, Muddy Creek, Pettis Co. (4); Cave Spring, Morgan Co. (8); Roaring River, Barry Co. (9); Lake, Mountain Grove, Wright Co. (7); Pond, Current River, Van Buren, Carter Co. (7); Branch, Spring River, Carthage, Jasper Co. (6); Stream, Peirce City, Lawrence Co. (10); Lake, Peirce City (15); Nevada, Vernon Co. (5); Daviess Co. (6); Cooper Co. (7); Swamp, Scott Co. (6); Springfork Creek, Camden Co. (14); Grand Falls, Jasper Co. (3); Lake, Clinton, Henry Co. (13); Callaway Co. (Greger); Blees Academy lake, Macon, Macon Co. (9).

Postpliocene:—Bluff City Landing (Hambach).

49. PLANORBIS SAMPSONI Ancey.

Pond, Flat Creek, Pettis Co., type lot (4); Same place, May, 1883, (3); Same place, Aug., 1886, (25); Same place, July, 1889, (15); Flat Creek, Pettis Co. (6); Bowsher's Spring, Mercer Co. (3); Coelleda, Camden Co. (1).

For some years this species was abundant in a pond on Flat Creek near Sedalia, from which the type specimens came, but when the locality of the pond was put in cultivation the pond dried up and that locality was exhausted. A few specimens have been found in Flat Creek near by, a single one in Camden county, a larger size in a spring in Mercer county, some at Athens, in Illinois, and lately at one place in Arkansas.

50. PLANORBIS EXACUOUS Say.

Pond, Flat Creek, Pettis Co. (68).

This and the next were found in the same small pond with *Planorbis sampsoni.*

51. PLANORBIS PARVUS Say.

Pond, Pettis Co. (21).

52. PLANORBIS ARMIGERUS Say.

Mouth of Wolf River (Hambach).

LYMNÆIDÆ.

LYMNÆINÆ.

PSEUDOSUCCINEA Baker

51. PSEUDOSUCCINEA COLUMELLA Say.

Flat Creek, Pettis Co., 1881, (7); Lake, Mountain Grove, Wright Co. (1); Pettis Co. (8); Branch of Spring River, Carthage, Jasper Co. (1).

52. Pseudosuccinea columella chalybea Gld.

Crandall's fountain, Sedalia, Pettis Co., 1882, (29); Flat Creek, Pettis Co., 1884, (13); Blees Academy lake, Macon, Mo. (3).

53. Pseudosuccinea columella casta Lea.

Branch of Flat Creek, Pettis Co. (1).

galba Schrank.

54. Galba bulimoides techella Hald.

Spring on bluffs, Kansas City, Jackson Co. (25).

55. Galba parva Lea.

Flat Creek, Pettis Co. (4); Pettis Co. (4); Leucke's quarry, Pettis Co. (6); Springfield, Greene Co. (12); Branch, Pettis Co., May 30, 1885, (7).

56. Galba humilis modicella Say.

Stream, Peirce City, Lawrence Co. (4); Coelleda, Camden Co. (15); Springfork, Pettis Co. (26).

57. Galba obrussa Say.

Livingston's pond, Douglas Co. (11); Spring Branch, Douglas Co. (24); Spring Branch, Ste. Genevieve Co. (6); Lamar, Barton Co. (3); Branch, Madison Co. (1); Pond, Peirce City, Lawrence Co. (3); Roaring River Spring, Barry Co., 1881, (10).

58. Galba obrussa exigua Lea.

Roaring River Spring, Barry Co. (14).

59. GALBA CATASCOPIUM Say.

Flat Creek, Pettis Co. (1).

ACTEOPHILA.

AURICULIDÆ.

CARYCHIUM Müller.

60. CARYCHIUM EXIGUUM Say.

Sedalia, Pettis Co. (10); Providence, Boone Co. (100).

61. CARYCHIUM EXILE H. C. Lea.

Providence, Boone Co. (25).

STYLOMMATOPHORA. Monotremata, Vasopulmonata, Orthurethra.

VALLONIIDÆ.

VALLONIA Risso.

62. VALLONIA PULCHELLA Müll.

Sedalia, Pettis Co. (50); Providence, Boone Co. (75); Columbia, Boone Co. (50).

In Sedalia at the crossing of the two principal streets, a vacant lot had stones piled upon it, and for a time this shell was found there in great numbers. At Providence, in local drift by the side of the railroad tracks, in about a quart of material, I found this and a large number of other small shells, in all more than a thousand shells. Postpliocene fossils were abundant close by, but I could not find any of these small ones imbedded in the ground with the fossils, and think they were of living shells, though most of them were bleached.

63. Vallonia gracilicosta Reeve.

Providence, Boone Co. (7).

64. Vallonia parvula Sterki.

Providence, Boone Co. (10).

Pupidæ.

strobilops Pils.

65. Strobilops labyrinthica Say.

Sedalia, Pettis Co. (15); Providence, Boone Co. (100); Nevada, Vernon Co. (2); Lamar, Barton Co. (2); Morgan Co. (1); St. François Co. (2); Camden Co. (3); Jaspar Co. (5); Columbia, Boone Co. (2); Callaway Co. (Greger).

Postpliocene:—St. Louis (Hambach).

pupoides Pfeiffer.

66. Pupoides marginata Say.

Sedalia, Pettis Co. (200); Jasper Co. (24); Springfield, Greene Co. (4); Ash Grove, Same Co. (3); Nevada, Vernon Co. (10); Seligman, Barry Co. (25); Galena, Stone Co. (33); Washington Co. (5); Iron Mt., St. François Co. (4); Jackson, Cape Girardeau Co. (1); Camden Co. (20); Greenfield, Dade Co. (12); Mt. Vernon, Lawrence Co. (3); Chouteau Springs, Cooper Co. (1); Columbia, Boone Co. (35); Paris, Monroe Co. (4); Jefferson City, Cole Co. (3); Fern Glen, St. Louis Co. (1); Callaway Co. (Greger); Gallatin, Daviess Co. (5).

bifidaria Sterki.

67. Bifidaria armifera Say.

Sedalia, Pettis Co. (63); Jasper Co. (11); Springfield, Greene Co. (4); Ash Grove, Same

Co. (2); Nevada, Vernon Co. (15); Monett, Lawrence Co. (3); Warrensburg, Johnson Co. (1); Warsaw, Benton Co. (2); Morgan Co. (1); California, Moniteau Co. (7); Columbia, Boone Co. (24); Chouteau Springs, Cooper Co. (6); Jefferson City, Cole Co. (18); Macdonald Co. (1); Greenfield, Dade Co. (4); Camden Co. (27); Golden City, Barton Co. (2); Cassville, Barry Co. (1); Douglas Co. (21); Iron Mt., St. François Co. (17); Potosi, Washington Co. (1); Paris, Monroe Co. (15); Fern Glen, St. Louis Co. (10); Seligman, Barry Co. (Pilsbry); Chadwick, Christian Co. (Pils. & Ferriss); Callaway Co. (Greger); Gallatin, Daviess Co. (5).

Postpliocene:—St. Joseph, Buchanan Co. (1); Near St. Louis (Hambach).

68. Bifidaria contracta Say.

Sedalia, Pettis Co. (25); Lamar, Barton Co. (15); Golden City, Same Co. (56); Nevada, Vernon Co. (3); Jasper Co. (15); Springfield, Greene Co. (1); Warsaw, Benton Co. (1); Moniteau Co. (5); Columbia, Boone Co. (4); Camden Co. (3); Paris, Monroe Co. (1); Chouteau Springs, Cooper Co. (1); Providence, Boone Co. (225); Iron Mt., St. François Co. (5); Seligman, Barry Co. (Pils.).

69. Bifidaria pentodon Say.

Warsaw, Benton Co. (1); Sedalia, Pettis Co. (13); Lamar, Barton Co. (5); Camden Co. (1); Jasper Co. (Vanatta & Pils.).

70. Bifidaria pentodon floridana Dall.

Lamar, Barton Co. (1).

71. Bifidaria holzingeri Sterki.

Jasper Co. (1); Providence, Boone Co. (40).

72. Bifidaria procera Gld.

Sedalia, Pettis Co. (25); Nevada, Vernon Co. (var.) (1); Providence, Boone Co. (54); Jefferson City, Cole Co. (2).

vertigo Mull.

73. Vertigo gouldii Binney.

Providence, Boone Co. (11).

Cochlicopidæ.

cochlicopa Fer.

74. Cochlicopa lubrica Müll.

Seligman, Barry Co. (Pils.).

HETERURETHA.

Elasmognatha.

Succineidæ.

succinea Drap.

75. Succinea ovalis Say.

Providence, Boone Co. (4), (4); Callaway Co. (Greger).

Postpliocene:—Glasgow, Howard Co. (var.) (5); Bluff City Landing (Hambach).

One lot from Providence was from low ground in the river bottom, and the shells were 18 mm. long.

76. Succinea retusa Lea.

Columbia, Boone Co. (3); Barry Co. (2); Saline Co. (8).

77. Succinea avara Say.

Near Georgetown, Pettis Co. (6), (11); Flat Creek, Same Co. (11); Columbia, Boone Co. (13); Chouteau Springs, Cooper Co. (9); Porter Springs, Morgan Co. (5); Camden Co. (1); Springfield, Greene Co. (3); Jackson, Cape Girardeau Co. (4).

Postpliocene:—Glasgow, Howard Co. (3).

78. Succinea avara vermeta Lea.

Columbia, Boone Co. (8).

79. Succinea grovenori Lea.

Iron Mountain, St. François Co. (1); Carthage, Jasper Co. (1); Columbia, Boone Co. (17); Pettis Co. (9); Same Co., July 4, 1883, (4); Georgetown, Same Co., May, 1884, (24).

Postpliocene:—St. Joseph, Buchanan Co. (Extreme form) (6); very large form (10).

80. Succinea concordialis Gld.

Sedalia, Pettis Co. (23); Muddy bridge, Georgetown, Same Co. (13); Pettis Co., May, 1883, (18); Columbia, Boone Co. (11); Golden City, Barton Co. (1); Jackson, Cape Girardeau Co. (1); Providence, Boone Co. (3).

81. Succinea obliqua Say.

Bluff City Landing (Hambach).

82. Succinea campestris Say.

Bluff City Landing (Hambach).

Holopoda.

Helicidæ.

polygyra Say.

83. Polygyra leporina Gould.

Monett, Barry Co. (2); Cape Girardeau Co. (2); Neeleyville, Butler Co. (2).

84. Polygyra fraudulenta Pils.

Fern Glen, St. Louis Co. (15); Allanville, Cape Girardeau Co. (3); Kimmswick, Jefferson Co. (1).

The peristome is not reflected backward and rounded as in *neglecta,* but is widely reflected and directed inwards forming a basin-shaped mouth. The upper tooth on the lip is the broader, and generally slightly bifid, and is on the edge, contrary to the type description. The specimens are 13 to 17 mm. diameter, and in one case, in which a shell had been injured and repaired, only 12 mm. The only difference between these and *neglecta* seems to be in the size and the diameter of the umbilicus. In these the umbilicus extends to the apex of the first whorl, but it is not wide enough to see the whorls to the apex, while in *neglecta* it is. The Allanville shells are the larger, up to 17½ mm. diameter. All are flatter than Indiana specimens.

85. Polygyra neglecta Pils.

Carthage, Jasper Co. (7); Cassville, Barry Co. (12); Seligman, Barry Co. (P & F.); Springfield, Greene Co. (P. & F.); Chadwick, Christian Co. (P. & F.).

Many of the specimens at Eureka Springs, Arkansas, are albinos, but this is not often the case with the Missouri shells. At Cassville they were 10 to 10½ mm. diameter, but from Carthage they were markedly larger, 12 to 13 mm. The inferior lip tooth is somewhat the larger, is more prominent on the front part of the lip, and in some cases is bifid.

86. Polygyra vultuosa Gould.

Sedalia, Pettis Co.; Boonville, Cooper Co. (1).

Years ago I found on Flat Creek near Sedalia, a single shell that I with another compared very carefully with this species, and had no doubt of the identification, but the specimen has been lost. A single shell in the collection is marked with a question mark as from Boonville. In a later hunt I hoped to find another but did not do so. The shell is not quite mature, but is believed to be this species.

87. Polygyra crageni Call.

Dade Co. (1); Split Log, Macdonald Co. (1); Mt. Vernon, Lawrence Co. (1).

These would formerly have been included in *vultuosa*, but are now separated under the above name.

88. Polygyra inflecta Say.

Poplar Bluff, Butler Co. (7); St. François Co. (3); Marble Hill, Bollinger Co. (3); Madison Co. (3); Seligman, Barry Co. (7); Fern Glen, St. Louis Co. (3); River Bluffs, Moniteau Co. (10); Providence, Boone Co. (5); Boonville, Cooper Co. (21); Camden Co. (2); Morgan Co. (9); Sedalia, Pettis Co. (14); Warsaw, Benton Co. (10); Galena, Stone Co. (6); Carthage, Jasper Co. (15); Macdonald Co. (7); Chadwick, Christian Co. (Pilsbry & Ferriss); Cure-

all Springs, Howell Co. (Walker Coll.); Jefferson City, Cole Co. (Walker Coll.); Ironton, Iron Co. (1); Cape Girardeau, Cape Girardeau Co. (?); Ste. Genevieve, Ste. Genevieve Co. (2); Callaway Co. (Greger).

Postpliocene:—Providence, Boone Co. (12).

89. Polygyra inflecta media Pils.

Pilsbry reports finding at Seligman specimens with normal teeth and also with teeth very much reduced, which he called variety *media*. All the shells I found there have normal teeth.

90. Polygyra profunda Say.

Postpliocene:—Providence, Boone Co. (10); Lupus, Moniteau Co. (10); Lexington, Lafayette Co. (Hambach).

I have not found living specimens of this species in the State.

91. Polygyra albolabris Say.

Postpliocene:—One-half mile below Great Nemaha (Hambach).

92. Polygyra albolabris alleni Weth.

Pettis Co. (11); Jefferson City, Cole Co. (3); McAllister Springs, Saline Co. (5); Camden Co. (3); Morgan Co. (2); Warsaw, Benton Co. (3); Columbia, Boone Co. (13); Kansas City, Jackson Co. (4), (19); Barry Co. (2); Scott Co. (1); Madison Co. (1); Shepard Mountain, Iron Co. (1); Cape Girardeau, Cape Girardeau Co. (6); Galena, Stone Co. (3); River bluffs, Moniteau Co. (3); Birmingham, Clay Co. (6); Chadwick, Christian Co. (Pils. & Fer.); Selig-

man and Monett, Barry Co. (P. & F.); DeSoto, Jefferson Co. (Pils.); Bethany, Harrison Co. (Walker Coll.); St. Charles Co. (4).

Postpliocene:—Lupus, Moniteau Co. (7); Providence, Boone Co. (10).

The specimens very generally show the characteristics of the variety *alleni*. Those from one locality in Kansas City are noticeable for their small size. The following will show the sizes of some found in an old cemetery, and of some dead shells found on the bluff above the Union station:

Diameter.	Cemetery.	Bluffs.
18 mm.	2	
18.5	2	
19	11	
19.5	7	
20	20	1
20.5	8	
21	16	
21.5	6	
22	7	
22.5	5	
23	5	1
23.5	1	2
24	1	1
24.5		1
25	1	1
27		1

From Galena the specimens were from 26 to 30 mm. diameter; from Scott county 32 mm., and the postpliocene from Providence 23 to 33 mm.

93. Polygyra divesta Gould.

Dade Co. (5); Seligman, Barry Co. (1); Carthage, Jasper Co. (3); Camden Co. (1); Chadwick, Christian Co. (Pilsbry); Springfield, Greene Co. (Pils.); Cedar Gap, Wright Co. (Pils.); Mt. Vernon, Lawrence Co. (Walker Coll.).

Postpliocene:—St. Joseph, Buchanan Co. (5).

94. POLYGYRA ZALETA Binney.

Fern Glen, St. Louis Co. (9); Vineland, Jefferson Co.

Those from Fern Glen could not be distinguished from Ohio specimens if mixed with them. They are up to 29 mm. diameter. In 1898 Frank C. Baker identified some shells collected at Arcadia, among them *Polygyra zaleta.* Whether these were the present *zaleta* or the *zaleta ozarkensis* is uncertain.

95. POLYGYRA ZALETA OZARKENSIS Pils.

Columbia, Boone Co. (1); Moniteau Co. (1); Camden Co. (3); Roaring River, Barry Co. (1); Cassville, Barry Co. (2); Macdonald Co. (2); Galena, Stone Co. (4); Current river, county not given, (Pils. & Fer.); Cedar Gap, Wright Co. (Pils. & Fer.); Chadwick, Christian Co. (Pils. & Fer.); Springfield, Greene Co. (Weller); St. François Co. (Walker Coll.).

96. POLYGYRA MULTILINEATA Say.

Boonville, Cooper Co. (1).

In August, 1911, I found a single dead but fresh shell on the river bluff above the bridge at Boonville, the only one I have found in the State. It is 20 mm. in diameter.

Postpliocene:—Glasgow, Howard Co. (4); Near Mouth of Big Nemaha and Platte rivers (Hambach).

97. POLYGYRA APPRESSA Say.

New Madrid Co. (7); River bottom, Scott Co. (1); Benton, Scott Co. (7); Poplar Bluff, Butler Co. (2); St. François Co. (2); Madison Co. (3); Cape Girardeau, Cape Girardeau Co. (11); Allanville, Cape Girardeau Co. (13); Ste. Genevieve, Ste. Genevieve Co. (17); Kimmswick,

Jefferson Co. (1); Fern Glen, St. Louis Co. (5); Morgan Co. (6); Jefferson City, Cole Co. (14); River bluffs, Moniteau Co. (13); McBaine, Boone Co. (9); Providence, Boone Co. (7); Boonville, Cooper Co. (28); Bear Creek, Marion Co. (20); Pineville, Macdonald Co. (Walker Coll.); Pettis Co. (Walker Coll.); Arcadia, Iron Co. (Baker); St. Louis (Smithsonian Coll.); Callaway Co. (Greger).

Postpliocene:—Providence, Boone Co. (22), (12); Lupus, Moniteau Co. (15).

Those from the southern counties are of heavier and coarser striæ than the others, but the specimens from the river bottom in Scott county have much less prominent striæ than those from Benton in the same county. In all of the lots are found specimens with a single lip tooth, and others with two, and sometimes one without either. Pilsbry has defined *appressa* (Nautilus, Volume VII, p. 140) as having no microscopic spiral lines, but this was criticised by Wetherby. However, in none of the above are found the microscopic lines as given in the type description.

Those from New Madrid county are the largest, 17 to 21 mm.; from Jefferson City they are 15 to 16 mm., with fine striæ. From the river bluffs in Moniteau county one would expect the same size as at Jefferson City, but they are distinctly larger, 16 to 18 mm. At Boonville, also on the Missouri river, they are from 14 mm., and a number of the shells do not have the umbilicus covered. This is markedly so also of a shell from St. François county. From Ste. Genevieve the shells are very much like those from central Missouri. The Cape Girardeau shells vary from the small, light colored, very finely striated, to the larger dark colored coarsely striated form. One shell shows that by some injury a part of the shell was broken away, and a new lip more than a half whorl short of the original one formed. Both teeth remain, the old one

more than a half whorl beyond the later one. The Allanville shells resemble the larger of those from Cape Girardeau, but are distinctly different, and of a deeper reddish color. Pilsbry says he has seen some Arkansas and Illinois specimens similar but not so dark.

The postpliocene shells from Providence vary from 15 to 21½ mm. diameter.

98. Polygyra elevata Say.

Bear Creek, Marion Co. (8); Jefferson City, Cole Co. (3); Barry Co. (1); Camden Co. (4); Columbia, Boone Co. (6); Moniteau Co. (1); Galena, Stone Co. (7); Fern Glen, St. Louis Co. (2); Pettis Co. (Walker Coll.); Springfield, Greene Co. (Walker Coll.); Callaway Co. (Gregger); St. Charles Co. (3); Missouri City, Clay Co. (1).

Postpliocene:—Lupus, Moniteau Co. (11); Providence, Boone Co. (15).

99. Polygyra pennsylvanica Greene.

Jackson, Cape Girardeau Co. (1); Fern Glen, St. Louis Co. (1).

Postpliocene:—Providence, Boone Co. (4).

The Fern Glen shell looks very much like a postpliocene fossil, but I think it is not such.

100. Polygyra thyroides Say.

Scott Co., upland, (1); Same, river bottom, (7); Jackson, Cape Girardeau Co. (2); St. François Co. (4); Marble Hill, Bollinger Co. (2); Poplar Bluff, Butler Co. (4); New Madrid Co. (2); Van Buren, Carter Co. (1); Camden Co. (3); Morgan Co. (1); Moniteau Co. (6); Boonville, Cooper Co. (11); Pettis Co. (10), (1); Carthage,

Jasper Co. (3), (2); Columbia, Boone Co. (10); McAllister Springs, Saline Co. (1); Bear Creek, Marion Co. (2); Galena, Stone Co. (1); Fern Glen, St. Louis Co. (2); Seligman, Barry Co. (Pils.); Chadwick, Christian Co. (Pils.); Birmingham, Clay Co. (4); Rockville, Bates Co. (Walker Coll.); Cureall Springs, Howell Co. (Walker Coll.); Vineland, Jefferson Co. (Baker); Tuscumbia, Miller Co. (1); North Jefferson, Calloway Co. (3).

Postpliocene:—Lupus, Moniteau Co. (1); Providence, Boone Co. (12); Bluff City Landing (Hambach).

From the river bluffs at Boonville they are uniformly small in size; from Boone county they are 20 to 26 mm. in diameter, and from Scott county up to 27 mm.

101. Polygyra clausa Say.

Barry Co. (3); Cassville, Barry Co. (5); Springfield, Greene Co. (2); Peirce City, Lawrence Co. (10); Carthage, Jasper Co. (7); Douglas Co. (2); Dade Co. (1); Pettis Co. (10); Kansas City, Jackson Co. (4); Blue Lick, Saline Co. (2); Jackson, Cape Girardeau Co. (1); Boonville, Cooper Co. (3); Birmingham, Clay Co. (13); Galena, Stone Co. (2); Fern Glen, St. Louis Co. (3); Chadwick, Christian Co. (Pils. & Fer.); St. Louis (Lind.); Arcadia, Iron Co. (Baker); Callaway Co. (Greger); Dent Co. (7); St. Charles Co. (1).

Postpliocene:—Providence, Boone Co. (2); Near mouth of Big Nemaha and Platte rivers (Hambach).

102. Polygyra labrosa Bland.

Macdonald Co. (6); Dade Co. (6); Carthage, Jasper Co. (1); Camden Co. (2); Benton Co.

(2); Galena, Stone Co. (7); Springfield, Greene Co. (3); Seligman, Barry Co. (Pils. & Fer.); Chadwick, Christian Co. (Pils. & Fer.); Marble Cave, Stone Co. (Pils. & Fer.); Cedar Gap, Wright Co. (Fer.).

From Macdonald county the shells are 10 mm. diameter; from Dade county only 9 mm. The body whorl is so constricted behind the peristome that the greatest diameter is not from a point on the lip, but on the whorl back of it.

103. Polygyra hirsuta Say.

Kansas City, Jackson Co. (4); River bluffs, Moniteau Co. (11); McAllister Springs, Saline Co. (16); Pettis Co. (16); Boonville, Cooper Co. (1); Columbia, Boone Co. (6); Jackson, Cape Girardeau Co. (1); Allanville, Same Co. (3); Scott Co. (?); Marble Hill, Bollinger Co. (1); Warsaw, Benton Co. (1); Fern Glen, St. Louis Co. (1); Jefferson City, Cole Co. (Walker Coll.); Callaway Co. (Greger); St. Louis Co. (1).

Postpliocene:—Providence, Boone Co. (3); St. Joseph, Buchanan Co. (1); Near St. Louis (Hambach).

Pilsbry says this has not been found south of Sedalia, Missouri, where I reported it some years ago. Jackson, and other places from which it is now reported are south of Sedalia, and the specimens are of this species; they certainly are neither *blandiana* nor *uncifera*. The shell from Jackson is more globose, of something more than five whorls, and the body whorl much more ventricose than in typical specimens. The striæ of increase are scarcely visible on the body whorl, but on the others show some bands of light color. The Allanville shells are larger than the Jackson.

104. Polygyra blandiana Pils.

Springfield, Greene Co. (6); Seligman, Barry Co.

The Springfield specimens were received from J. H. Ferriss. Pilsbry reports it from both the above localities.

105. Polygyra stenotrema Fer.

Douglas Co.

106. Polygyra monodon Rauck.

St. François Co. (1); Laclede Co. (2); Morgan Co. (1); Moniteau Co. (9); Sedalia, Pettis Co. (20); Boonville, Cooper Co. (11); Saline Co. (4); Clinton, Henry Co. (12); Warrensburg, Johnson Co. (8); Mound City, Holt Co. (10); Callaway Co. (6); Dade Co. (1); Lamar, Barton Co. (2); Monett, Barry Co. (10); Lawrence Co. (13); Jasper Co. (7); Camden Co. (3); Albany, Gentry Co. (Walker Coll.); St. Louis Co. (3); Gallatin, Daviess Co. (6).

Postpliocene:—Providence, Boone Co. (12); St. Joseph, Buchanan Co. (7); St. Louis (Hambach).

Those from Monett seemed to be imperforate, but on close examination a very small umbilical opening can be seen. The same is true of those from Callaway county. One shell from St. Louis county is very noticeable in having a very wide and prominent umbilicus, the peristome rounding to and connecting with the parietal tooth, and not entering into the umbilicus.

107. Polygyra fraterna Say.

Fern Glen, St. Louis Co. (1); Marble Hill, Bollinger Co. (1); Scott Co. (2); Camden Co. (1); Boonville, Cooper Co. (15); River bluffs, Moni-

teau Co. (11); Warsaw, Benton Co. (1); Pettis Co. (1); Columbia, Boone Co. (7); Birmingham, Clay Co. (13); Ste. Genevieve, Ste. Genevieve Co. (4); Taborville, St. Clair Co. (Walker Coll.); Milan, Sullivan Co. (Same); Clinton, Henry Co. (Same); Callaway Co. (Greger).

At Boonville some specimens were intermediate in size between *monodon* and *fraterna*. In Bollinger county the one specimen found was 9 mm. diameter, but from Scott county in the same part of the State they were only 7½ mm.

108. Polygyra fraterna alicia Pils.

Mineral Point, Washington Co. (1); Farmington, St. François Co. (3); Rivermines, Same Co. (6); Paris, Monroe Co. (6).

109. Polygyra fraterna friersoni Pils.

Jefferson City, Cole Co. (Walker Coll.).

110. Polygyra fraterna imperforata Pils.

Ste. Genevieve, Ste. Genevieve Co. (6); Cape Girardeau, Cape Girardeau Co. (1).

111. Polygyra dorfeuilliana Lea.

Fern Glen, St. Louis Co. (9); Hunter, Carter Co. (3); Howell Co. (3); Douglas Co. (2); Ironton, Iron Co. (1); Arcadia, Iron Co. (Baker); Stone Co. (Stearns); Neosho, Newton Co. (Walker Coll.); Pineville, Macdonald Co. (Walker Coll.); Cureall Springs, Howell Co. (Walker Coll.); Henry Co. (Pils. & Fer.); Callaway Co. (Greger).

112. Polygyra dorfeuilliana sampsoni Weth.

Warsaw, Benton Co. (25); Camden Co. (13); Barry Co. (13); Grand Falls, Jasper Co. (7);

Macdonald Co. (10); Springfield, Greene Co. (Pils. & Fer.); Chadwick, Christian Co. (P. & F.); Current river, Co. not given, (P. & F.); Seligman, Barry Co. (Pils.); Arcadia, Iron Co. (Baker).

These different lots vary somewhat in the distinctness of sculpture on the under side, in the size and position of the upper lip tooth, and in the flatness of the vault, but apparently not uniformly so or distinct enough to deserve a varietal name.

113. Polygyra jacksoni Bland.

Camden Co. (10); Dade Co. (10); Barry Co. (13); Ash Grove, Greene Co. (12); Grand Falls, Jasper Co. (1); Split Log, Macdonald Co. (1); Cassville, Barry Co. (1); Springfield, Greene Co. (P. & F.).

114. Polygyra triodontoides Bland.

Monett, Barry Co. (2).

Bulimulidæ.

bulimulus Leach.

115. Bulimulus dealbatus ozarkensis Pils. & Fer.

Cooper Co. (8); Camden Co. (5); Barry Co. (2); Macdonald Co. (5); Douglas Co. (2); Rivermines, St. François Co. (1); Oakwood, Marion Co. (2); Callaway Co. (Greger); Cass Co. (8).

Stearns reported *B. dealbatus* from Stone county. When I found this shell in Cooper county I thought that this was the most northern point in the State where it would be found, and I was much surprised afterwards to find it near Hannibal.

CIRCINARIIDÆ.

CIRCINARIA Beck.

116. CIRCINARIA CONCAVA Say.

Pettis Co. (2); Columbia, Boone Co. (6); Poplar Bluff, Butler Co. (3); St. François Co. (1); New Madrid, New Madrid Co. (1); Camden Co. (1); Scott Co. (1); Fern Glen, St. Louis Co. (7); Moniteau Co. (2); Macdonald Co. (4); Bear creek, Marion Co. (1); Galena, Stone Co. (1); Kansas City, Jackson Co. (1); Chadwick, Christian Co. (Pils. & Fer.); Callaway Co. (Greger).

Postpliocene:—Lupus, Moniteau Co. (6); Providence, Boone Co. (8); Near St. Louis (Hambach).

ZONITIDÆ.

ZONITINÆ.

OMPHALINA Rafinesque.

117. OMPHALINA FULIGINOSA Griff.

Scott Co. (4); Carthage, Jasper Co. (1); Jackson, Cape Girardeau Co. (1); Macdonald Co. (2); Seligman, Barry Co. (2); Warsaw, Benton Co. (2); Marble Hill, Bollinger Co. (1).

Pilsbry and Ferriss say that the early whorls of *fuliginosa* are invariably white, the cuticle being worn off. This is the case with all of the above except that from Marble Hill, but it is not full grown and is of only 3½ whorls. They describe a variety *fuliginosa ozarkensis,* which has fine spiral striæ, but none of the above show such lines.

118. OMPHALINA FRIABILIS W. G. B.

Cape Girardeau, Cape Girardeau Co.

These shells are of large size, up to 28 mm. diameter, and with apex entirely unworn.

VITREA Fitz.

119. VITREA INDENTATA Say.

New Madrid Co. (2); Cape Girardeau Co. (2); St. François Co. (14); Potosi, Washington Co. (3); Mineral Point, Same Co. (4); Howell Co. (1); Douglas Co. (4); Galena, Stone Co. (1); Laclede Co. (1); Mt. Vernon, Lawrence Co. (13); Peirce City, Same Co. (2); Greenfield, Dade Co. (15); Golden City, Barton Co. (7); Morgan Co. (2); Sedalia, Pettis Co. (20); Warrensburg, Johnson Co. (2); Jasper Co. (16); Camden Co. (23); Clinton, Henry Co. (5); River bluffs, Moniteau Co. (3); Split Log, Macdonald Co. (2); Moniteau Co. (5); Fern Glen, St. Louis Co. (1); Paris, Monroe Co. (1); Seligman, Barry Co. (Pilsbry); Arcadia, Iron Co. (Baker); Monett, Barry Co. (Pils. & Fer.); Chadwick, Christian Co. (Pils. & Fer.); Gallatin, Daviess Co. (2).

Postpliocene:—Below mouth of Platte river (Hambach).

120. VITREA HAMMONIS Strom.

Sedalia, Pettis Co. (46); Clinton, Henry Co. (4); Monett, Barry Co. (2); Columbia, Boone Co. (2); Seligman, Barry Co. (Pils.); Chadwick, Christian Co. (Pils. & Fer.).

121. VITREA SIMPSONI Pils.

Pilsbry and Ferriss identify a small race of the above at Chadwick, Christian county.

EUCONULUS Reinh.

122. EUCONULUS FULVUS Drap.

Sedalia, Pettis Co. (13); Lamar, Barton Co. (1); Dade Co. (1); Galena, Stone Co. (1); Golden City, Barton Co. (4).

ARIOPHANTINÆ Pils.

ZONITOIDES Lehmann.

123. ZONITOIDES ARBOREUS Say.

New Madrid, New Madrid Co. (1); St. François Co. (35); Jackson, Cape Girardeau Co. (25); Scott Co. (11); Poplar Bluff, Butler Co. (2); Bloomfield, Stoddard Co. (10); Galena, Stone Co. (4); Monett, Barry Co. (26); Springfield, Greene Co. (7); Douglas Co. (5); Lamar and Golden City, Barton Co. (34), (74); Jasper Co. (28); Aurora, Mt. Vernon & Peirce City, Lawrence Co. (15), (19), (1); Nevada, Vernon Co. (3); Warsaw, Benton Co. (1); Clinton, Henry Co. (89); Warrensburg, Johnson Co. (2); Saline Co. (5); Morgan Co. (3); Split Log, Macdonald Co. (5); California, Moniteau Co. (19); Chouteau Springs, Cooper Co. (26); Laclede Co. (9); Mound City, Holt Co. (18); Sedalia, Pettis Co. (74); Camden Co. (61); Greenfield, Dade Co. (2); Missouri river bluffs, Moniteau Co. (2); Ash Grove, Greene Co. (1); Grand Falls, Jasper Co. (2); Potosi, Washington Co. (9); Ironton, Iron Co. (2); Chadwick, Christian Co. (2); Callaway Co. (Greger).

Postpliocene:—St. Louis (Hambach).

PSEUDOHYALINA Morse.

124. ZONITOIDES MINUSCULUS Binn.

Sedalia, Pettis Co. (3); Clinton, Henry Co. (2); Warsaw, Benton Co. (3); Nevada, Vernon Co. (4); Jasper Co. (3); Lamar, Barton Co. (2); Douglas Co. (2); Mt. Vernon, Lawrence Co. (4); Potosi, Washington Co. (1).

GASTRODONTA Albers.

125. GASTRODONTA LIGERA Say.

Neeleyville, Butler Co. (4); New Madrid, New Madrid Co. (12); River bluffs, Moniteau Co. (7); Boonville, Cooper Co. (14); Sedalia, Pettis Co. (5); McAllister Springs, Saline Co. (5); Columbia, Boone Co. (9); Bear Creek, Marion Co. (5); Fern Glen, St. Louis Co. (3).

Postpliocene:—Providence, Boone Co. (1).

126. GASTRODONTA DEMISSA BRITTISI Pils.

Pilsbry and Ferriss doubtfully identify some specimens from Chadwick, Christian county with the above.

ENDODONTIDÆ Pilsbry.

ENDODONTINÆ.

PYRAMIDULA Fitzinger.

PATULA Hald.

127. PYRAMIDULA ALTERNATA Say.

Columbia, Boone Co. (25); Paris, Monroe Co. (15); Bear Creek, Marion Co. (1); Mound City, Holt Co. (2); Birmingham, Clay Co. (7); McAllister Springs, Saline Co. (11); Kansas City, Jackson Co. (5); Dade Co. (8); Pettis Co. (10); Morgan Co. (2); Golden City, Barton Co. (2); Carthage, Jasper Co. (6); Camden Co. (5); Jackson, Cape Girardeau Co. (5); Scott Co. (6); Marble Hill, Bollinger Co. (2); Madison Co. (7); Poplar Bluff, Butler Co. (7); St. François Co. (8); Allanville, Cape Girardeau Co. (17); Peirce City, Lawrence Co. (1); Arcadia, Iron Co. (Baker); North Jefferson, Callaway Co. (12); St. Louis Co. (2); Cooper Co. (4).

Postpliocene:—Providence, Boone Co. (17); Glasgow, Howard Co. (5); St. Joseph, Buchanan Co. (9); Bellevue (Hambach); Lexington (Hambach).

The collection has a sinistral shell from near Columbia, the first reverse land shell I have found in the State.

128. PYRAMIDULA SOLITARIA Say.

St. François Co. (3); Bollinger Co. (1); Fern Glen, St. Louis Co. (1); Morgan Co. (1); Camden Co. (6); Pettis Co. (6); River bluffs, Moniteau Co. (10); Columbia, Boone Co. (6); Bonne Terre, St. François Co. (Walker Coll.); Cooper Co. (Walker Coll.); Callaway Co. (Greger); Dent Co. (1); St. Charles Co. (5).

Postpliocene:—Providence, Boone Co. (22); Lupus, Moniteau Co. (8).

I have specimens from Indiana 28½ mm. diameter, while those from Pettis county are only 22.

GONYODISCUS Fitz.

129. PYRAMIDULA PERSPECTIVA Say.

St. François Co. (13); Madison Co. (1); Marble Hill, Bollinger Co. (12); Jackson, Cape Girardeau Co. (15); Poplar Bluff, Butler Co. (9); Benton, Scott Co. (9); Seligman, Barry Co. (8); River bluffs, Moniteau Co. (4); Cureall Springs, Howell Co. (Walker Coll.); Chadwick, Christian Co. (Pils. & Fer.).

Postpliocene:—Providence, Boone Co. (1).

HELICODISCUS Morse.

130. HELICODISCUS LINEATUS Say.

Sedalia, Pettis Co. (20); Warsaw, Benton Co. (4); Nevada, Vernon Co. (2); Dade Co. (5);

Laclede Co. (3); Moniteau Co. (1); Douglas Co. (2); Golden City, Barton Co. (5); St. François Co. (8); Cassville, Barry Co. (1); Columbia, Boone Co. (1); Providence, Same Co. (100); Paris, Monroe Co. (5); Gallatin, Daviess Co. (2).

Postpliocene:—Mouth of Platte river (Hambach).

PUNCTINÆ.

PUNCTUM Morse.

131. PUNCTUM PYGMÆUM Drap.

Providence, Boone Co. (4).

132. POLYGYRA ANDREWSI W. G. B.

St. François Co.

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VARIATIONS IN THE EARTH'S MAGNETIC FIELD.*

FRANCIS E. NIPHER.

On account of the possibility of local disturbance due to street cars, it was thought desirable to repeat some of the work described in a former paper in these Transactions, No. 2, Vol. XXII. This was done during the summer of 1913 in a large tent 18x20 ft. located on the lake shore at the north end of Lake Huron. The station was about 50 ft. from the lake and about half a mile N. W. of the village of Hessel, in Mackinac County.

The magnetic needle was a piece of knitting wire 7 cm. in length, suspended upon a fiber of unspun silk about 40 cm. in length. The enclosing case was formed from a large glass bottle, the top of which was removed. A metal cap fitting closely around the top of the glass jar thus formed, was provided with a vertical brass tube, having at its top a torsion head and means for attaching the suspension fiber. This metal cap was sealed to the glass jar by means of adhesive rubber tape. The jar was mounted in a closely fitting base provided with leveling screws, which were about 30 cm. apart, in order to secure stability. A fine copper wire soldered to the middle of the needle, served as a means for attaching the suspension fiber. It also extended below the needle, and to its lower end was attached a horizontal wire about 6 cm. in length, which dipped into coal oil in the bottom of the jar, and served as a damper for the needle. Attached to the wire suspension of the needle was a small mirror, by means of which the motion of the needle was observed, in the usual way with a tele-

*Presented before The Academy of Science of St. Louis, October 20, 1913.

scope and scale. The scale was divided into centimeters and tenths. The scale value was 1 *mm*=3.37 minutes of deflection of the needle.

The structure upon which the needle and telescope were mounted, was a frame constructed of 2x4 inch timber bolted together with brass bolts, and the legs or corner posts of the frame extended two feet down into clay and gravel soil. The structure was braced longitudinally and transversely, the braces being held in place by large brass screws. The structure thus formed was 8 ft. in length in a north and south direction with respect to the magnetic meridian, and 4 ft. in width.

The needle was deflected 90° from the magnetic meridian, by means of two bar magnets 2 ft. in length whose axes made an angle of 45° with the meridian. The resultant field was thus the same as the horizontal component of the earth's field. This resultant field was then partly compensated by two bar magnets 4 ft. in length, on either side of the needle, and at the ends of the table, about 4 ft. distant from the needle. The final resultant field in which the needle was thus placed was about 0.05 that of the horizontal component of the earth's field. This was determined by the oscillation method, before the damping liquid was introduced. The time of vibration was corrected for the torsional effect of the suspension fiber.

With this arrangement, the needle is very sensitive to changes in the horizontal component of the earth's field, and it has the advantage of permitting these changes to be observed at any instant. Some preliminary observations were made with the control magnets exposed to the air. The tent was provided with a fly, which permitted a free circulation of air between it and the roof. It however became evident that the variation in position of the needle was materially influenced by a variation in the temperature of the magnets, although the maximum temperature of the day during July and August did not exceed 85° F. This temperature effect was

greatly reduced by wrapping the magnets in heavy padded blankets. It was, however, soon eliminated by maintaining all of the control magnets at a temperature of 32° F. This was done by placing each magnet within a piece of heavy rubber tubing. This tubing was of strong fiber, coated within and without with rubber. The ends were plugged and sealed with wax. The tubes with the enclosed magnets were mounted in V-shaped supports within boxes put together by means of copper nails, and calked. The boxes were then filled with fragments of ice, packed closely around the rubber tubes. The ends of the boxes rested on the side timbers of the frame so that the blankets could be wrapped around the boxes. The boxes were provided with outflow tubes of brass.

The maintaining of the control magnets at a fixed temperature, diminished the daily swing of the magnetic needle in a very appreciable degree. It did not apparently affect the character of the changes due to wind-gusts and cloud shadows. It did, however, serve to remove all possible doubt from the conclusions. In this series of observations, it was not the object to make precise measurements of the quantities involved. It was a search for fundamental phenomena. For precise measurements the two sets of magnets might each be replaced by two coils as in the Helmholtz-Gaugain galvanometer. These might be mounted on a table capable of rotating around a vertical axis coincident with the suspension fiber. Two telescopes with scale mounted 90° apart upon the table would serve to properly adjust the table when both circuits were open, and to deflect the needle 90°. The current in the deflecting coils would be increased until the telescope with axis east and west is directed upon the reading corresponding to the magnetic axis of the needle, as determined by the other telescope, the torsion head being turned 90°.

The current and the constant for the coils being known, the value of H is determined at that instant. The resultant field could then be decreased to any desired

amount by closing the circuit containing the compensating coils, and varying the current by means of a proper resistance (carbon plates with a compression screw).

It was of course found that in general the intensity H of the horizontal component of the earth's field, increases during the day, reaching a maximum late in the afternoon. The numerical value of H is, however, greater on clear days than on cloudy days. On days which are clear in the forenoon and cloudy in the afternoon, the maximum may occur in the middle of the day, or before noon. During days when the air is quiet, the needle is more quiet during cloudy or clear days, than when the sky is covered with small clouds with blue sky between.

On days when the wind blows in gusts at intervals of one or two minutes the needle is more unsteady in its movements, than on quiet days, or on days when the wind is more uniform.

On days when gusts of wind are frequent, it is impossible to identify any particular wind-gust with any particular disturbance of the needle. The reason for this appears to be explained by an observation made on July 14. During the forenoon of that day the wind was very mild from the west. Shortly before 1 o'clock the wind suddenly changed to the south, while it continued at the rate of 3 to 4 miles per hour. At 1:10 p. m. the needle began to vibrate to and fro. The scale reading at each extreme position was recorded. This was continued for nine minutes, when a blast of wind came in from the lake to the south. It overturned a sail boat lying at a dock about 200 ft. distant, the sails of which had been raised in order to dry them. It was by far the most violent wind of the summer. About eight minutes later the wind had practically ceased, and the vibrations of the needle had also ceased. The scale reading had been under constant observation before the gust of wind began. The reading was recorded each minute, and even more frequently during times of mild disturbance, when slow to and fro movements made this necessary. When

the movement was apparently uniform in one direction, records were made at intervals of five or ten minutes, although the needle was under almost constant observation.

During the oscillations above referred to, the watch reading was taken at as frequent intervals as was possible. In these oscillations the time of one to and fro vibration was about 50 seconds, as nearly as it could be determined. The time covered by consecutive vibrations frequently varied so greatly on other occasions that no precise value could be given for the time of vibration. The effect of the damping liquid was such that the needle would come practically to rest in three or four semi-vibrations when deflected 90°.

These vibrations above described are graphically shown in Plate XXI. The instant when the blast of wind reached the observing station is indicated by the arrow, located near the middle of the group of vibrations representing this local magnetic storm. The ordinates are in scale divisions. The greatest amplitude of swing was about 20 scale divisions. The hour of the day is laid off upon the horizontal axis. The fact that the needle was affected by this air disturbance south of the station at least nine minutes before it reached the station, is in exact harmony with the suggestion given in the former paper in these Transactions referred to above. As was there pointed out, a brush which disturbs iron filings at any point on a plate of glass above a bar magnet, is producing an ether disturbance in the field of that magnet. This observation also shows clearly, why it is that on stormy days, when gusts of wind follow each other at frequent intervals, the effect due to any one gust cannot be identified. At any instant, the needle responds to a summation of these disturbances.

It could hardly be expected that such a wind disturbance could produce a magnetic storm of more than a local character. But it is not at all improbable that tor-

nadoes and tropical cyclones may produce much more wide-spread effects. A wind disturbance among the atmospheric ions which sometimes accumulate along the magnetic lines of force at the earth's magnetic poles, might be expected to produce the effects which have long been observed.

On ten or twelve occasions similar effects were observed, which were caused by a local dash of rain. When rain falls continuously or at intervals during a day when the sky is covered with clouds, which extend over adjoining states, the needle shows no appreciable disturbance. The horizontal component of the earth's field is then much weaker than it would be if the sky were clear, but there is no additional change due to a rainfall. The limiting condition has been already reached.

When small clouds are scattered over the sky and a local fall of rain occurs at the observing station, the sunlight passing through the air through which the raindrops fall, a very marked magnetic storm is produced. Such a disturbance is represented in Plate XXII.

This rain, which was very violent, began while I was at the noon-day meal. It lasted about ten minutes. When the tent was reached the rain had practically ceased at the station. The sun was visible during most of the time while the rain was falling. The area covered by the rain was probably not over one or two square miles. Its boundary could be seen upon the lake to the south, while I was on the way to the tent. The needle showed that we were then in the midst of one of the most violent magnetic storms of the summer. The vibrations ceased about five minutes after observation began. The extreme reading of the scale for each oscillation was taken. They are represented in Plate XXII, together with subsequent readings of the needle represented on the same time scale. Readings made before leaving the tent for lunch are also shown. The gap between the readings before and after lunch is only in part represented, as is indicated by the figures at the bottom of the

plate representing the hour of the day. The needle was in a more disturbed condition after the vibrations had ceased than it had been before. Evidently the rain had some effect upon the magnetic field at the station when it was falling through air to the south of the station, and had ceased at the station. The needle was damped during this day, so that summation effects were impossible, nevertheless in one of these oscillations the needle vibrated through an arc of over 5°.

This rain occurred on August 26. A diagram representing the movement of the needle between 10 a. m. and sunset, is presented in Plate XXIII. The vibrations due to the rain occurred at the close of the first gap in that curve. They cannot be properly represented here with the time-scale used in this plate. They are replaced by a straight line. The second gap in the diagram represents the time required to finish the noon-day meal, which had been interrupted by the rain. The part of the diagram of Plate XXII, after the hour of 1:05, is the part which in Plate XXIII lies between the two gaps.

Plate XXIII also represents the effect upon the horizontal component of the earth's field, of two large dense and sharply defined clouds passing over the sun. Their effect is shown at points corresponding to 11:10 a. m. and 4:28 p. m. During seven weeks the needle had been under constant observation, from sunrise to sunset, in order to secure the results which were here obtained. On many days evidence of cloud effects were observed which seemed conclusive, but usually the edges of the cloud would not be sharply defined. In some cases the edges would be more or less transparent, in some cases small clouds of irregular form would surround the larger cloud. It often happened that large dense clouds appeared to be approaching the sun, and the needle gave results which were wholly different from those which had been expected. On going out of the tent it would be found that the cloud had behaved in a wholly different manner from what had been expected. In some cases it

practically disappeared before it reached the sun. Sometimes it was dispersed into smaller clouds, which were more or less hazy in outline. Their effect might be appreciable and persuasive, and yet more or less unsatisfactory.

The fact that it was impossible to predict at what moment the desired conditions might present themselves, and the necessity for having a record of the behavior of the needle for a considerable time interval before the sun entered a dense cloud, made it necessary to keep the needle under constant observation, recording the results during each minute of the day, sometimes at lesser intervals, so far as this was possible. The only interruption to this work during July and August was from August 12th to 16th, during which interval a severe attack of a painful illness made work of any kind impossible.

The sun entered the well defined edge of the first cloud above referred to at 10:45 a. m. The needle had been previously moving continuously in a direction such as would be caused by a steady increase in the strength of the field. When the sun entered the cloud, irregularities in the movement of the needle were observed. The air on the border of a cloud shadow often gave evidence of a disturbed condition. In this case the sun was in the center of the cloud at about 11:10 a. m. This cloud then covered the overhead sky down to about 45° from the horizon. Below this cloud the sky was clear. The sun reappeared at 11h 12m 30 sec. At this time the scale reading corresponded to the minimum shown in the diagram, Plate XXIII. The needle at once reversed its direction of movement. The reading at 11:40 or 11:50 was, as the diagram shows, about what it would have been if the cloud had not appeared.

This cloud was soon afterwards broken up into smaller clouds, and other smaller clouds appeared. From 12:30 to 2 p. m. the sky was partly covered here and there by smaller clouds, so that at the station, as at surround-

ing points, the sun was visible at and during frequent intervals. One of these small clouds unexpectedly gave rise to the dash of rain before discussed. The general effect of these clouds is shown in the general drop in the curve between 12:30 and 1:30 p. m.

The sun entered another dense and sharply defined cloud surrounded by clear sky, at 4:20 p. m. of this same day, after the daily maximum had been passed. It emerged from this cloud at 4:28 p. m. While the sun was hidden by this cloud, the intensity of the magnetic field diminished as in the other case, as is shown by the drop in the curve. When the sun reappeared the intensity at once began to increase. At 4:37 the reading was that corresponding to the general trend of the curve during that afternoon. The time of entering and leaving the cloud is in both cases indicated on the diagram by arrows.

It would thus appear that cloud shadows during the day have the same effect upon the earth's magnetic field that the earth's shadow has at night. The lines of the field sway around them. They sway above the clouds into the sunlight. The horizontal component would thus be diminished below the clouds.[1]

It is impossible to present here the full evidence obtained, which to me seems to establish beyond all question the conclusion that local variations in the earth's magnetic field are determined wholly by local weather conditions. It is contained in 300 pages of closely written notes on pages 8 inches square. While it might at first seem that the greater part of this record was of no importance, it does establish the general conclusion that when local conditions were uniform, whatever they might be, the magnetic needle showed no marked disturbance of an abrupt character, such as we have in these vibrations.

[1] Observations of the character here discussed should be made during solar eclipses.

It may suffice to discuss briefly the record of July 19. In doing this the weather maps kindly furnished by the Weather Bureau at Washington were of material assistance. On the afternoon of this day, the needle showed more disturbance than on any other day. At 10 a. m. a rain cloud was observed in the southern horizon. At 11:45 the needle began to vibrate, the average amplitude of vibration being about 20 scale divisions, and sometimes reaching 35. The wind, which had been from the northwest, had changed to the south. This continued until about 12:10 p. m., when the needle became less disturbed, and observations ceased until 12:45 p. m. During this disturbance, it could be seen that a rain was falling on the lake to the south. At 12:45 a violent dash of rain began, which continued for ten minutes, and then continued as a milder rain until 1:05. The clouds were not continuous over the sky. The sun appeared at intervals.

The point of importance is that these vibrations began and continued for an hour, while a rainstorm existed to the south of the station, and before rain began to fall at the station. During the remainder of the afternoon periods of sunshine and rain came in alternation. Between 2:37 and 3:10 over half an inch of rain fell, from what appeared to be a local cloud. The needle continued to vibrate during this rain, and after it had ceased at the station and while its roar could be heard upon the lake to the south. The wind was very mild during the entire day, its velocity not at any time exceeding 8 or 10 miles per hour. The amplitude of the vibrations sometimes reached 40 scale divisions. The greatest amplitude of the day was 49 scale divisions. The needle was damped during this day.

The data given on the weather map show that the rain which visited the observing station extended from Escambia, which is in northern Michigan, near the north end of Lake Michigan, to Alpena, which is in southern Michigan, near the north end of Lake

Huron. At the former station the rainfall was 0.44 inch and at the latter it was 0.36 inch. At Saginaw, Mich., which is south of Alpena and also on the west side of Lake Huron, the rainfall was 0.26 inch. At Sault Ste. Marie, at the outlet of Lake Superior, no rain fell. This rainstorm was a purely local one, extending across the head of Lake Michigan and along the straits of Mackinac, and probably into Lake Huron.

On July 16, 26, 27 and 31 similar local rains occurred in the same region during the midday hours. In some cases there was practically no rainfall at Hessel, but the clouds which were observed near the horizon were recognized as rain clouds. The weather maps show that rain fell at surrounding weather stations. On all of these days, the needle was in to-and-fro vibration at intervals during the day. In all cases when the weather maps show rains in this region, which occurred during the hours of observation of the needle, the needle showed such vibrations.

On three days they were observed when violent gusts of wind occurred at the station, with no rain in that part of the country.

On August 23, very marked and sudden changes in the position of the needle were observed, and they were so unusual as to lead to the suspicion that something unusual must have happened. There were no vibrations accompanying those disturbances. The day was unusually clear. Very light rains occurred at all of the nearest weather stations, the greatest fall, 0.20 inch, being at Houghton, about 200 miles distant in a direction a little north of west.

On August 8, a violent rain accompanied by a continuous roar of overhead thunder occurred between 4 and 6:30 a. m. The needle was then very quiet, as was the case on every morning of the summer with one exception. On this morning when a few oscillations occurred after sunrise, they were accompanied by violent gusts of wind.

On two or three occasions phenomena were observed which suggested that winds from the north, reaching the station through a grove of trees, had a slightly different effect from that of a wind from the lake. This subject requires additional attention.

Perhaps the most interesting phenomenon observed during the summer was the continuous vibration of the needle during a period varying from half an hour to two hours preceding sunset. This was observed on nearly every evening when the western sky was clear. The vibrations were greatest when the day had been clear, and the intensity of the field had reached a high maximum. They did not occur when the afternoon sky was covered with a dense cloud. The cloud shadow is then joined to the earth's shadow. They did not occur in the morning, either before or after sunrise. Observations were sometimes begun as early as 2 o'clock a. m. They were usually begun about an hour before sunrise.

Plate XXIV, made from observations on August 31, gives an illustration of these sunset disturbances. The plate shows how the needle moved during the afternoon, before the oscillations suddenly began. In the original drawing, this part of the curve was drawn to a time scale of 6 cm. per hour. For the period during which the oscillations are represented, the time scale is 6 cm. to about 3 minutes. One to and fro oscillation was drawn to each half-centimeter. During this day the damping liquid had been removed. It will be observed that the disturbing cause ceased at about 5:45 and the needle gradually came to rest. On this day two similar violent disturbances occurred subsequently before sunset, which are not represented in Plate XXIV. The greatest amplitude reached was about 250 scale divisions, or about 14° of arc. The extreme scale reading for each and every vibration was read.

In nearly all of the observations on this sunset disturbance, the motion of the needle was restrained by the damping fluid. The amplitude of the vibrations was

then in general over an angle not exceeding 50 scale divisions or 2.8 degrees. The time of vibration was practically the same whether the damping fluid was used or not. It was not uniform in either case. The vibration of the damped needle frequently continued without cessation for an hour or more. At this hour of the evening there was usually no wind at the station.

It is evident that along what may be called the sunset meridian, there will generally be places where cloud shadows are joined to the earth's shadow. Since only the horizontal component of the earth's field of force is effective in action upon the needle, we may consider the conditions which would exist in a field of force in which the lines are horizontal. Where the clouds occur, these lines tend to sway above the clouds into the sunlight. If we consider these lines to behave like elastic threads, they are elongated by this distortion. They snap asunder and disappear as they are thus distorted and forced towards the approaching shadow of the earth, the field diminishing in strength in a rhythmical way. This statement must be considered as figurative in character, but it is in a certain sense descriptive of the observed phenomena. It is with some surprise that I find that this sunset disturbance has not been observed at stations where continuous records are made. This conclusion obtained from an examination recently made of government publications has been confirmed by information just received from the chief of the U. S. Coast and Geodetic Survey. Evidently the subject deserves additional attention.

It will of course be understood that the fact that wind-gusts a few miles distant are found to affect a magnetic needle, is in harmony with the well-known fact that solar disturbances also affect it.

The observation of Young at Sherman, Idaho, on August 3, 1872, showed that a solar outburst produces electromagnetic waves, which travel with the velocity of

light.[2] The effect on the magnetic needle at Greenwich and Stonyhurst was recorded at the same instant, that a solar disturbance was observed by Young (within the instrumental errors). Such results should lead us to expect that wind-gusts in air ionized by sunlight or by solar dust, as has been pointed out by Arrhenius, should produce similar results of a more local character.

In 1823, Barlow[3] made an experimental study of the diurnal variation of the earth's magnetic field. He deflected the needle into an east and west position, by means of two control magnets, lying in the magnetic meridian, acting upon opposite ends of the needle. At his request, his associate, Christie, continued the work. The effect of the earth's field was in part compensated by a magnet parallel to the dip needle. Their papers are in sequence in the Phil. Trans. of the Royal Society for 1823. Barlow gives his conclusion as follows:

"It appears to me that the quantity of daily change depends in a greater degree on the intensity of the solar light, than on the mere temperature of the day, although it is certain from some recent experiments of Mr. Christie, that the change of temperature of the air during the day, has a much greater effect upon the intensity of the opposing magnets than I could possibly have imagined."

Christie varied the temperature of the control magnets by placing upon them paper moistened with cold and with hot water. He concluded from the effect thus produced upon the magnets, that temperature, if not the only cause, is the principal cause of the daily variation in the earth's field.

A part of the work of both Barlow and Christie was done in their gardens, and the remainder in their houses,

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[2] The Sun. By Young, p. 158.

[3] Barlow should not be forgotten. He was the first to make an electric motor. Barlow's wheel is the rotating armature of an electric motor. Eight years later Faraday reversed this toy motor, and produced the first electrical generator. Neither of these men realized what he had accomplished.

which were about a mile apart. Both found great differences in the daily variation indoors and in open air, and various possible causes for it are discussed. Barlow concludes that it is probably due to the cause discovered by Christie, that the intensity at any point in the field of a bar magnet depends upon the temperature of that magnet. He ascribes this difference to the different temperature conditions of the control magnets. Nevertheless he is of the opinion that the quantity of daily change in the earth's field depends in a greater degree upon the intensity of solar light, than upon the mere temperature of the day. Evidently his intuitive faculty was of a high order.

Barlow's conclusion did not carry with it any rational explanation of causes, since at that time ionization of the air, by sunlight, resulting in an increase of its permeability, was unknown. The work of Christie also raised a doubt in the minds of others. Subsequent writers seem to have found it necessary to say that the daily variation and local magnetic storms had not been satisfactorily explained.

During the last fifteen years the present writer has made various attempts to produce a local magnetic storm in the earth's field by means of small amounts of high power explosives. The results discussed in the present paper seem to indicate beyond question that such explosions are capable of producing magnetic disturbances. The effect of the gust of wind shown in Plate XXI was to produce an ether disturbance extending far beyond and in advance of any air waves, or air disturbance.

Recent experiments with dynamite on the grounds adjoining the buildings of Washington University have not given conclusive results. It is difficult to eliminate other disturbances, and it is not permissible to use as large a quantity of the explosive as will probably be necessary. It is hoped that this work may be continued at Hessel during the coming summer.

Correction.—In Vol. XXII, No. 2, p. 59, line 1 from the top, erase *the* before Ampère.

EXPLANATION OF THE PLATES.

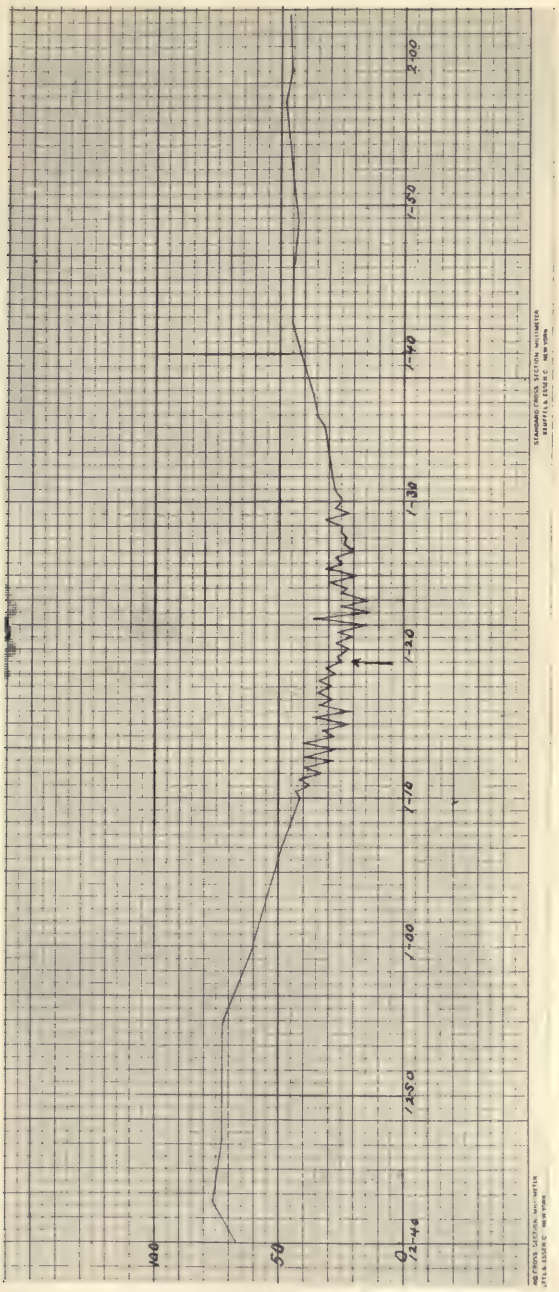
Plate XXI.—A local magnetic storm due to a local gust of wind of very unusual severity, lasting ten minutes, on a calm day. The wind storm reached the station nine minutes after the magnetic disturbance began, the time being indicated by the arrow.

Plate XXII.—A local magnetic storm due to a violent and very local fall of rain.

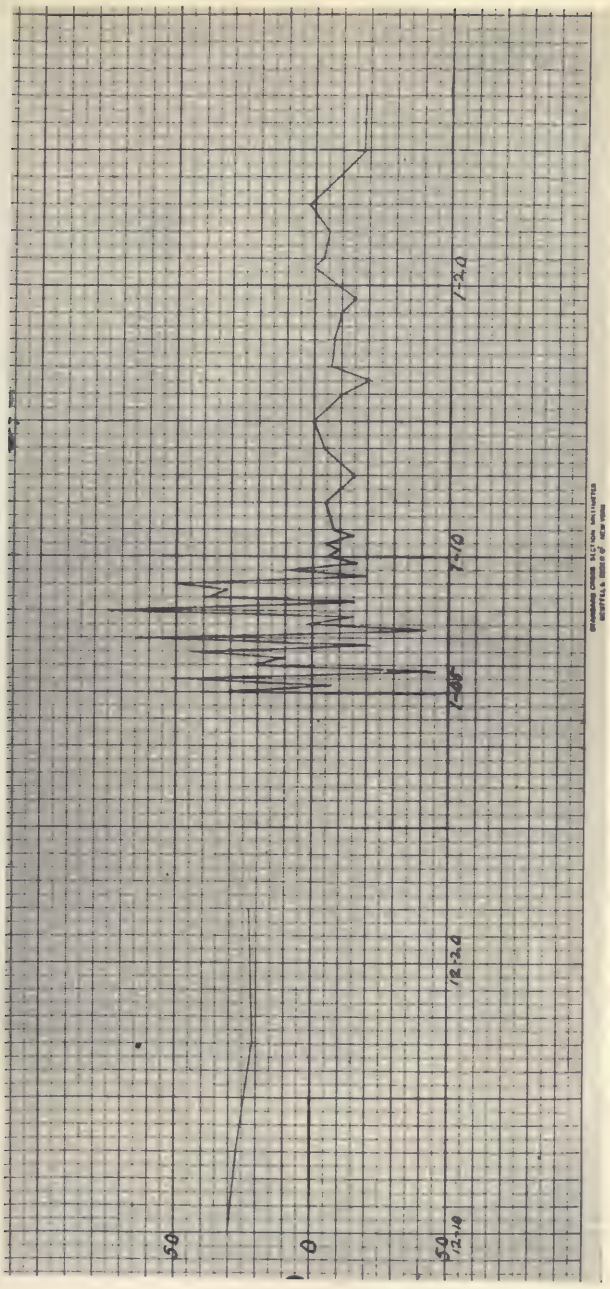
Plate XXIII.—A decrease in the horizontal intensity of the earth's magnetic field, due to two dense clouds surrounded by clear sky, passing over the sun, shown on the diagram at 11 a. m. and 4:30 p. m.

Plate XXIV.—A magnetic storm such as was observed usually on clear days shortly before sunset.

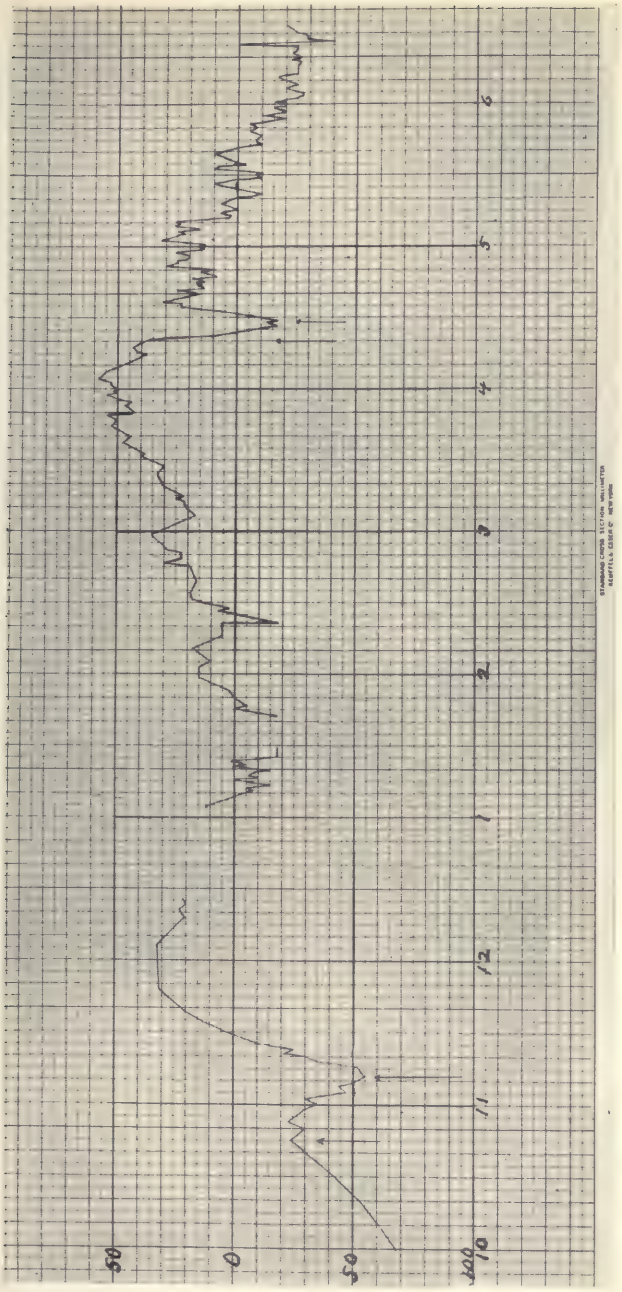
Issued October 3, 1913.



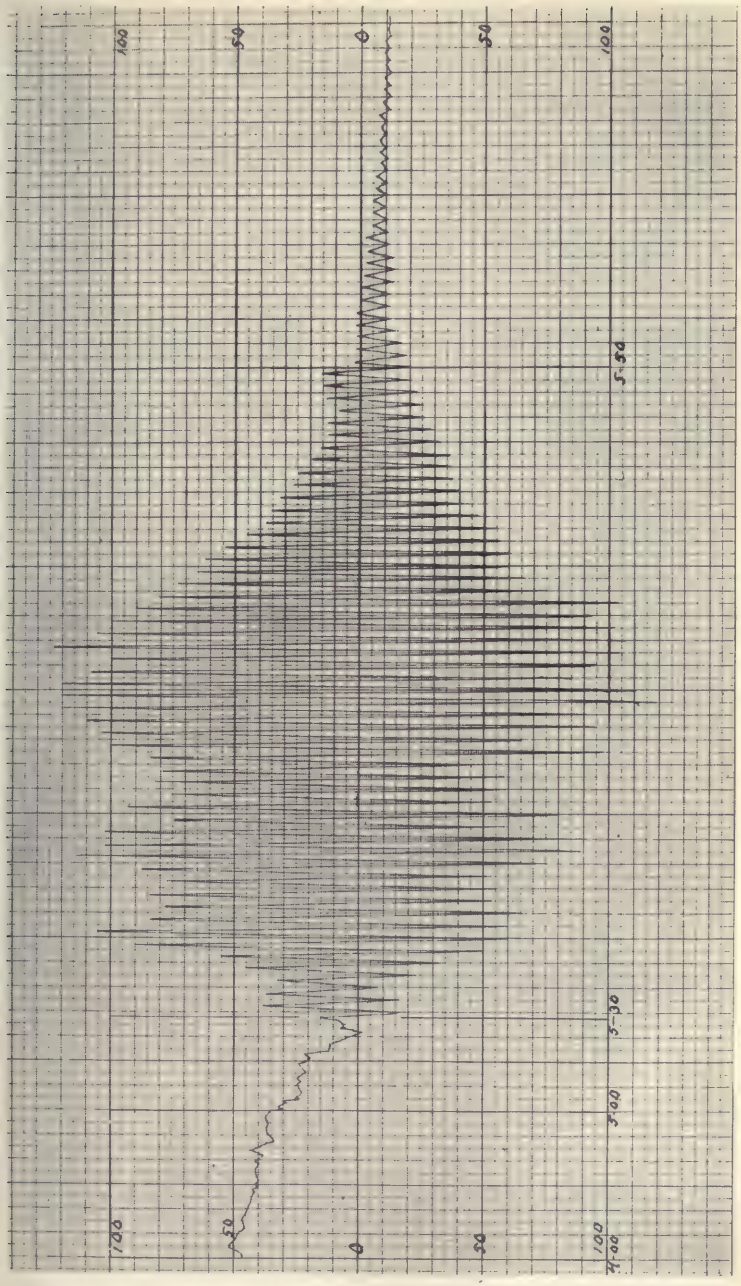
MAGNETIC STORM DUE TO WIND.



MAGNETIC STORM DUE TO RAIN.



EFFECT OF CLOUD SHADOWS.



MAGNETIC STORM AT SUNSET.

THE FLOWERS OF DIOSPYROS KAKI L. F.*

H. Harold Hume.

To quote from the usual descriptions of the genus *Diospyros* as given in American texts, the flowers are "dioecious, rarely polygamous" and though both staminate and pistillate flowers are accurately described, no mention is made of the characteristics or peculiarities of the perfect flowers, though the persimmon has three kinds of flowers, namely, perfect, staminate and pistillate. This naturally leads to the belief that the perfect flowers are indeed rare in the American species, *D. virginiana* and *D. texana.* A careful examination of many trees of the former species, while in bloom, has resulted in finding none so far and difficult as it would be to find such flowers on growing trees, it would be almost as difficult to detect their presence in herbarium specimens. Perhaps the easiest way to find them would be to locate, if possible, staminate trees which bear some fruit. A careful search of such trees during the next season might lead to their discovery. However the perfect flowers of an introduced species, *D. Kaki* have been found as detailed below.

On April 19, 1909, while pollenating flowers of *D. Kaki* with pollen of *D. virginiana,* staminate flowers of *D. Kaki* were first noticed on a tree of "Taber's No. 23" planted March 4, 1899. As the blooming period for this particular tree was nearly over, only six staminate flowers could be found, but a careful examination of the dried corollas on the ground beneath the tree showed that hundreds of these flowers had been produced, and in the tree, numerous small twigs were found with the peduncles of staminate flowers still adhering. Pistillate

* Presented by title to The Academy of Science of St. Louis, November 17, 1913.

flowers were also borne in large numbers and, as expected, the tree set a very heavy crop of fruit.

A note calling attention to these flowers and their possible value was published in *Science*.[1] The only certain reference to the staminate flowers of *D. Kaki* in American literature previous to this, by one acquainted with them, is by Berckmans,[2] who mentioned the occurrence of staminate flowers on young trees, but did not describe them and apparently attached no importance to their presence. Watts[3] may have seen them, but he leaves us in doubt. In describing the flowers of *D. Kaki* he says, "The flowers are inconspicuous, whitish green; the peduncles are usually three flowered. The flowers are complete, but all varieties are not equally self fertile." He makes no mention of the pistillate flowers, which are produced singly, and if by complete he meant that the flowers contained pistils and pollen bearing stamens, his observation was unusual, for perfect flowers are very scarce.

In European literature, the staminate flowers are described by Hiern,[4] Naudin[5] and Carriere[6] and mentioned by other writers.

In the spring of 1910, though a thorough examination of the same tree of "Taber's No. 23" was made, not a single staminate flower could be found. On younger trees of the same and of other varieties, however, they were found. The examination of trees, while in bloom, was continued through the blooming seasons of 1911, 1912,

[1] Hume, H. Harold. Non-fruiting of Japan Persimmons due to lack of Pollen. Science, N. S., Vol. XXX., No. 766, Sept. 3, p. 308-309. 1909.

[2] Berckmans, P. J. Persimmons. Cyclopedia American Horticulture, 3: 1281. 1901.

[3] Watts, R. L. Persimmons, University of Tennessee Agr. Exp. Station, Bulletin, Vol. XI., No. 1, Apr., p. 204. 1899.

[4] Hiern, W. P. A monograph of Ebenaceae. Transactions Cambridge Philosophical Society XII, Part 1, p. 227. 1872.

[5] Naudin, M. Ch. Quelques Remarques an sujet des Plaqueminiers (*Diospyros*) cultives a l' air libre dans les Jardins de L'Europe. Nouvelles archives du museum D' Histoire Naturelle 2" ser 3. 224. 1880.

[6] Carriere, E. A. Revue Horticole. 253-258, Plate, p. 254. 1872.

1913, with the result that staminate flowers have been discovered on several horticultural varieties, such as "Taber's No. 23," "Taber's No. 129," "Okame," "Masugata," "Siang" (S. P. I. 21910), "New Sien" (S. P. I. 22368), S. P. I. No. 27037 and an unknown variety found near Eagle Lake, Fla., which will be referred to as the Eagle Lake tree. On some of these varieties the appearance of staminate flowers is sporadic and influenced by unknown causes, while on other varieties they appear as regularly as the trees bloom.

So far as can be determined no mention has been made in either American or European literature of the occurrence of perfect flowers on *D. Kaki.* They are doubtless rare and our own observations are in accord with this belief. Perfect flowers were discovered in April, 1910, on three, different, two-year-old, "Okame" trees and on two trees of "Taber's No. 23" of the same age. In April, 1913, they were found on four-year-old trees of "Siang," and "Taber's No. 129" and on two-year-old trees propagated from the Eagle Lake tree. They are so different from either the staminate or pistillate flowers that when once known, they may be readily recognized by their external characters.

Location of Flowering Twigs.

All three types of flowers, of *D. Kaki,* are borne on shoots of the current season's growth and open shortly after the shoots and leaves are developed. In North Florida the blooming period usually occurs during the first three weeks in April. In some seasons it may begin as early as March 26th and it sometimes ends as late as May 7th. Delayed blooms may occasionally be found even at later dates.

The staminate flowers are usually borne on small, rather weak shoots which develop from lateral buds on last year's branches. On the strong vigorous twigs which develop from the buds at or near the end of the same branches, the pistillate flowers of the same trees

are usually borne. Sometimes, however, the two kinds of flowers occupy adjoining axils on the same twig. Occasionally the staminate flowers are found on vigorous twigs, particularly if pistillate flowers are entirely absent on shoots of a given branch. On "Taber's No. 129," the staminate flowers sometimes occupy the terminal shoots, and the pistillate, the lateral ones, especially if they are equally or nearly equally vigorous. The rule, however, is as already stated. The few staminate flowers so far found on "Okame" were all on short lateral twigs, and the same is true of the many flowers found on "Siang" (No. 21910). On "Masugata," "Taber's No. 129" and the Eagle Lake tree they are more frequently to be found on the vigorous twigs to which reference is made above.

Perfect flowers are usually associated with the staminate ones. Up to this time, they have not been discovered on any varieties of the fixed pistillate flowering type. In other words, it appears that the perfect flowers are a development from the staminate form and not from the pistillate form. When present, they are found more usually near the base of the strong and vigorous twigs which occasionally bear staminate flowers than on the short and comparatively weak lateral twigs on which the staminate flowers are generally found. Their development from the staminate form appears to be connected with the food supply.

Staminate Flowers.

Sometimes staminate flowers are produced in great profusion. They are borne normally in 3-flowered cymes in the axils of the bract-like leaves and normal leaves at the base of the twigs. Sometimes they appear at the very base of the twigs from flower buds located beneath the persistent scales of the last year's growth and occasionally on many flowered branches they are produced from last season's buds without apparent branch formation. Occasionally the cymes are four-flowered, some-

times two and at other times the flowers are produced singly. Particularly is this last true of the flowers at the very base of the twigs and also of those flowers which are sometimes located on pistillate flowering twigs.

The peduncles are 6 to 10 mm. long, slightly hairy, slender, curved downward, the secondary pedicels axillary in the axils of small linear early caducous bracts which are found on the main peduncle. These bracts are usually shed before the center flower of the cyme opens. The calyx is light green, sparsely hairy, four lobed, the lobes ¼ to ½ the length of the corolla-tube, thin, rounded at the points. The corolla is 9-14 mm. in length, light yellow, constricted beneath the reflexed lobes. These lobes are deep yellow and velvety on the upper surface, with margins minutely and sparsely hairy. If the ovary is entirely lacking the base of the corolla is closed and slightly pointed, but if the ovary is rudimentary and of some size, the base is open. The stamens are inserted on the corolla in two or three rows, 16 to 24 in number, the outer row or rows longer, the upper end of the anthers of the longer stamens reaching to and filling the throat of the corolla, anthers much longer than the very short hairy filaments. Pollen is produced abundantly and after being shed from the longitudinal slits in the anthers, it is held on the inner surface of the corolla in considerable quantities.

Occasionally a staminate and a perfect flower are found attached to the same peduncle, and sometimes a staminate flower is developed in one of the bracts on the pedicel of a pistillate flower.

The staminate flowers of "Okame" are not so pointed as are those of other varieties. The throat also is larger.

When the number of stamens is more than sixteen and less than twenty-four, the third or inner row of smaller stamens is only partially complete.

The peduncles of the staminate flowers are persistent through the summer and winter following the spring when they developed and are a satisfactory means of

determining whether a given tree produced staminate flowers.

Pistillate Flowers.

The pistillate flowers are solitary in the axils of the bract-like leaves and normal leaves near the base of the twigs. The flowers of "Tanenashi," "Okame," and "Tsuru" are very frequently found in the axils of the bract-like leaves, while the flowers of "Triumph," "Zengi" and "Costata," for example, are generally found in the axils of true leaves. Pedicels 14 to 32 mm. long, covered with minute hairs, curved so as to turn the opened flower downward, provided with two caducous bracts which are 2-3 mm. wide by 8-15 mm. long. The calyx is four parted, large, foliaceous, 25-35 mm. across the expanded lobes. The lobes are pointed or rounded, flattened or with margins reflexed, giving the lobes a more pointed appearance, nearly twice the length of the expanded corolla, outer surface minutely hairy; upper surface of calyx, close to and beneath the ovary covered with a dense hairy cushion. The corolla is 4 parted, light yellow, 10-17 mm. long, quadrangular with blunt angles, lobes reflexed light yellow on inner surface, constricted below the lobes, the throat usually somewhat quadrangular, margins of lobes minutely ciliate. The stamens are 8 in number clothed with fine white hairs, the pointed, abortive anthers curved inward over the ovary, filaments nearly as long as the anthers; ovary finally 8-celled, flattened, rounded or pointed, style sparsely hairy at the base, four parted upward; stigma much branched.

The stoutest pedicels observed are those of the variety "Zengi," 3-4 mm. in diameter; "Tsuru" has longer pedicels than any other variety noted, 20-32 mm. The location of the bracts on the pedicels of different varieties is worthy of note. In "Yemon," for instance, they are close to and often attached to the base of the ovary. On the pedicels of most varieties, the bracts are located about the middle of the pedicel.

The flowers of "Phelps" and "Triumph" are almost urceolate with rounded throat.

The pedicels of all varieties observed are very persistent and may still be found adhering on one and two-year-old and occasionally on three-year-old branches. The sex of a tree may be determined by their presence during the dormant and out-of-flower season.

The economy of the large foliaceous calyx on the pistillate flowers is quite apparent. It serves the same purpose as a leaf in preparing food for the tree, whereas the calyx of the staminate flower is small, of little value in this particular, and is early deciduous.

A careful microscopical examination of many hundreds of stamens of the true type of pistillate flowers has failed to show the presence of pollen in them.

Perfect Flowers.

The perfect flowers of *D. Kaki* are borne singly, in pairs or in three-flowered cymes usually near the base of vigorous shoots which frequently bear staminate flowers in the upper nodes, 13-20 mm. long. The pedicels are short 10-30 mm. long, medium stout, covered with minute hairs. The calyx is 4 parted, intermediate in development between the calyces of the staminate and pistillate flowers. The lobes are more pointed than in the pistillate flowers and often nearly as long as the corolla, smooth and shiny or with only a few scattered hairs. Corolla tubular, urceolate, rounded or quadrangular, resembling the corolla of the staminate flowers, but of greater diameter just above the base, constricted below the 4 recurved lobes, which are deep yellow on the inner surface. Stamens 16 to 24 (generally 16 to 18) in number with well developed pollen bearing anthers and short filaments, the anthers surrounding the stigma and projecting into the throat of the corolla. The ovary is more pointed than in the pistillate form on the same tree, 8-celled; pistil four parted; the stigmatic ends straight, and only slightly divided.

General Notes on the Development of the Flower Parts.

As already stated, the pistil in the staminate flowers, may be rudimentary or it may be entirely lacking, and it has been possible with the staminate, perfect and pistillate flowers to arrange a series ranging from flowers in which there is no sign of an ovary on one side, through to those containing the highest development of the ovary on the other. In such a series it will be noted that other parts of the flower vary in sympathy with the size of the ovary. The calyx is very small where the ovary is lacking, it is slightly larger in specimens having a rudimentary ovary, it is larger still in the perfect flowers and reaches its greatest development in the pistillate form. The corolla is smallest in those flowers having no pistil, its greatest transverse diameter is reached when the pistil increases to its maximum size. If the ovary is lacking, the corolla falls away from the calyx with its base closed, but if the pistil is rudimentary and of some size, the base is open. The opening in the base corresponds to the size of the ovary and varies with it, reaching its largest size in the pistillate flowers. Again in the staminate flowers the number of stamens is 16 to 24, in the perfect flowers usually 16-18 and in the pistillate flowers 8 are found. Broadly speaking, this variation may be stated thus:—when the size of the ovary decreases, the number of stamens increases, reaching the maximum number when the ovary is rudimentary or is lacking entirely.

Grouping Based on Flowering Habit.

Based on the behavior of persimmon trees in the production of flowers the varieties now growing in America may be divided into three groups,—(1) Those on which staminate flowers are never produced,—examples, "Tanenashi," "Tsuru," "Hachiya," "Hyakume," "Tri-

umph'' and ''Costata,''—(2) those on which staminate flowers occur sporadically,—examples,''Taber's No.23,'' ''Okame,''and ''Taber's No.129.'' And (3) those which bear staminate flowers as regularly as the trees bloom—examples, ''Masugata,'' ''Siang'' (S. P. I. No. 21910) and the ''Eagle Lake Tree.'' New ''Sien'' (S. P. I. No. 22368) and S. P. I. No. 27037 are not referred to these latter groups, as they are recent introductions and have come under observation this season (1913) for the first time. It is of course entirely possible that in China and Japan there are varieties of persimmons belonging to the species *D. Kaki* which bear staminate flowers only, and there is a remote though improbable chance that there are trees of which the flowers are all perfect.

The Importance of Pollen Bearing Flowers.

Since the Japan persimmons, *D. Kaki,* were introduced into the United States about forty years ago, there has always been something erratic in their behavior. It has been a common complaint on the part of nearly every one who has attempted their culture, that though the trees bloomed profusely, the young fruits dropped off shortly after the flowering season. At this period, each year, the ground under most trees is often literally covered with the calyces and ovaries of the flowers. At harvest time practically no fruit remains to be gathered. Here and there, for some hitherto unknown reason a tree or group of trees would hold a crop. This phenomenon is now known to be largely due to the unnoticed sporadic production of staminate flowers.

Needless to say, many reasons have been offered for the trees not bearing fruit. By some it was said to be due to improper cultivation, insufficient fertilizer, and lack of moisture. Others held just the opposite. Some even said it was peculiar to certain varieties, and that the growth of the calyces crowded the young ovaries off. All sorts of remedies to meet these different theories were advanced and tried, but in spite of all efforts to

correct the trouble, the Japan persimmons have continued to behave in the same manner.

While it is undoubtedly true that an unhealthy condition of the trees, due to the attacks of borers or other insect pests, or fungi and bacteria, and an insufficient supply of plant food, do effect the holding of a crop of fruit, yet it has been demonstrated that the large cause of the lack of fruitfulness in *D. Kaki* in the Southern and Southeastern states is due to lack of pollenation. It has likewise been amply demonstrated that staminate trees of *D. virginiana* will not serve as pollenizers, no artificial or hand pollenation between the two species having yet been made which resulted in viable seed.

Having in mind these facts, the value of the discovery of dependable varieties of *D. Kaki,* producing pollen bearing flowers, to act as pollenizers, becomes readily apparent. Of the varieties now commonly in cultivation, viz., "Costata," "Hachiya," "Hyakume," "Okame," "Taber's No. 23," "Taber's No. 129," "Tanenashi," "Triumph," "Tsuru," "Yeddoichi," "Yemon" and "Zengi," only one variety, "Tanenashi," a seedless variety, can be depended upon to produce a crop of fruit. This variety does not readily produce seed even when pollenated, hence the production of seedless fruit would not be affected by the proximity of staminate flowers. "Okame" and "Triumph" occasionally bear a fair amount of seedless fruit, but no reliance can be placed on them to do so each time they bloom. The others, and the two last mentioned, as well, are generally worthless unless pollen is provided to fecundate the blossoms. Nectar is secreted abundantly, the flowers are visited freely by bees and other insects, and the blooming periods overlap. Hence there is nothing to interfere with a revision of orchard and garden planting practice to insure the pollenation of *D. Kaki* flowers and the setting of fruit.

EXPLANATION OF THE PLATES.

Plate XXV.—Pistillate Flowers of *D. Kaki*, var. "Yemon." Natural size.

Plate XXVI.—Staminate Flowers of *D. Kaki*, var. "Tabers No. 129." Normal three flowered cymes in lower right-hand corner. Natural size.

Plate XXVII.—Perfect Flowers of *D. Kaki*, var. "Okame." Natural size. Solitary lower flower and upper three flowered cyme.

Plate XXVIII.—Staminate Flowers of *D. Kaki*, var. "Siang," on main central shoot. Two pistillate flowers, unopened, on lateral twig at right. All natural size.

Plate XXIX.—Young fruits of *D. Kaki*, var. "Taber's No. 129." Natural size. Three young fruits from pistillate flowers and one fruit from perfect flower on right hand twig. The latter is attached to same peduncle as the lowest fruit from pistillate flower. Fruit on twig on the right from perfect flower.

Plate XXX.—Fig. 1. Unopened Pistillate flowers of *D. Kaki*, var. "S. P. I. 22,362," showing bracts on the pedicels. Natural size.—Fig. 2. Unopened staminate flowers of *D. Kaki*, var. "Taber's No. 129," showing bracts on pedicels. Natural size.—Figs. 3 and 4. Pistillate and staminate flowers on same pedicel. *D. Kaki*, var. "Eagle Lake tree." Slightly enlarged.—Fig. 5. Two pistillate flowers on same pedicel, *D. Kaki*, var. "Yemon."

Plate XXXI.—Figs. 1-7. Series showing variation in development of calyces. All natural size.—1 and 2. No pistils present.—3 and 4. With small rudimentary pistils.—5. Rudimentary pistil present—quite large.—6. Perfect flower.—7. Pistillate flower.—8-15. Bases of corollas natural size, though No. 9 is an under size specimen.—8. Base of corolla without any sign of ovary.—9. Base of Pistillate flower. "Taber's No. 23."—10 and 11. Bases of perfect flowers, var. "Okame."—12. Corolla of staminate flower without ovary. Var. "Taber's No. 23."—13. Lobes and throat of staminate flower, var. "Taber's No. 23."—14. Corolla of staminate flower without ovary, var. "Taber's No. 129."—15. Lobes and throat of staminate flower, var. "Taber's No. 129."—16 and 17. Three flowered cymes, var. "Okame." Central ones perfect, lateral ones staminate. Natural size.—18. Three flowered cyme "Taber's No. 129." Natural size.—19. Four flowered cyme "Taber's No. 129." Natural size.—20. Two flowered cyme "Taber's No. 129," the central one natural size.—21. Opened corolla of perfect flower showing position and size of stamens. "Okame."—22. Part of corolla removed to show stames and pistil of perfect flower. "Okame." —23. Part of corolla of pistillate flower removed to show pistil and abortive stamens. "Okame."—24. Opened corolla of pistillate flower. "Okame."

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CORRECTIONS.

Page 208.—In lines 2, 5, and 18 from bottom, for 1,593,125 read 1,953,125.

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LONGEVITY IN SATURNIID MOTHS AND ITS RELATION TO THE FUNCTION OF REPRODUCTION.*

PHIL RAU AND NELLIE RAU.

INTRODUCTION.

If Nature's aim in the animal world be the improvement of the races, she must have a frequently changing medium upon which to operate; if it be merely their perpetuation, she may be satisfied with a few well favored individuals which live a long time. The first hypothesis concentrates attention upon the welfare of the race, the second on the welfare of the individual. But the purposes of Nature seem two-fold, both perpetuation and improvement of the stock.

It is obvious that the improvement would best be accomplished by the production of the maximum number of young in connection with a brief duration of life, thus giving a large number of tender individuals for Natural Selection to play upon, and many generations in a brief period of time through which to effect changes. This plan, however, could not hold good for all the members of the earth's animal population, for it would not permit of the development of size, strength and high differentiation of organisms—all these factors pertaining to the individual welfare.

A momentary mental survey of the animal world will tell us that a marked correlation exists between the length of life of individuals and the reproductive functions[1] of the various species, although we cannot say off-

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[1] Reproductive function includes brood-care.

hand which is the primary and which the secondary function, whether the length of life depends upon the rate of increase, or the rate of reproduction depends upon the length of the generations—in other words, whether approaching death incites reproduction, or reproduction causes death.

We desired to get at the principles of the duration of life from the standpoint of their efficiency for the perpetuation of the species. Hence we made an extensive study of the longevity of Saturniid moths, with a view to ascertaining just what relationship exists between the longevity and environment and the function of reproduction. These pages embody the results gleaned from the records kept of a large number of individuals of several species for a number of seasons, and from several localities.

The data are presented in the following sequence:[2]

INTRODUCTION.

LONGEVITY.
- PHILOSAMIA CYNTHIA.
- TELEA POLYPHEMUS.
- CALLOSAMIA PROMETHEA.
- SAMIA CALIFORNICA.
- SAMIA CECROPIA.
- DISCUSSION OF LONGEVITY.
- LONGEVITY UNDER CONDITIONS OF LOWERED TEMPERATURE.

OVIPOSITION.
- NUMBER OF EGGS CARRIED.
- COMPLETENESS OF OVIPOSITION.
- AGE WHEN FIRST EGGS WERE DEPOSITED.
- AGE AT WHICH THE GREATEST NUMBER OF EGGS WERE DEPOSITED.
- LAPSE OF TIME BETWEEN LAST OVIPOSITION AND DEATH.

PROPORTION OF SEXES.

THE PRIORITY OF MALE EMERGENCE.

THE FERTILITY OF SATURNIID EGGS IN RELATION TO THE MATING PERIOD.
- INTRODUCTORY REMARKS.
- SAMIA CECROPIA.

[2]Since it is not customary for the Academy to publish a table of contents of its articles, we hope that this syllabus may serve the purpose of locating each unit.

PHILOSAMIA CYNTHIA.
TELEA POLYPHEMUS.
SAMIA CALIFORNICA.
THE MINIMUM DURATION OF MATING IN RELATION TO FERTILITY.

THE PERIOD OF INCUBATION.
SAMIA CECROPIA.
TELEA POLYPHEMUS.
SAMIA CALIFORNICA.
PHILOSAMIA CYNTHIA.

MISCELLANEOUS DATA ON SATURNIID BIOLOGY.
BASILONIA IMPERIALIS.
PROBABLE TWO-BROODEDNESS OF T. POLYPHEMUS.
INFERTILITY OF POLYPHEMUS EGGS.
CROSSINGS.
EATING OF EGG-SHELLS BY T. POLYPHEMUS.
CALLOSAMIA PROMETHEA.
FLUFFY COCOONS OF S. CECROPIA.
DURATION OF PUPAL STAGE IN S. CECROPIA.
DURATION OF THE PERIOD OF COPULATION IN T. LUNA.
COCOON SPINNING.

SUMMARY.

GENERAL CONSIDERATIONS AND CONCLUSIONS.

In a previous paper[3] we have reviewed fully the theories which have been formulated to account for the duration of life. Finding the existing theories inadequate to account for the results of our experiments, we made some suggestions as to what observations should be carried on before one can philosophize on the meaning of the duration of life.

In the present work we have followed out some of the courses of investigation mentioned there. The material is similar, but in far greater numbers, and from a variety of localities. The technique is essentially the same. We must once more urge the reader to bear in mind that the Saturniid moths have aborted mouth parts, and at no time in the adult existence do they require or can they assimilate food. This factor renders these moths ideal material for such observations in so far as the duration

[3] Journ. Exp. Zool., 12: 179-204, 1912.

of their lives cannot possibly be influenced by insufficient or improper food. One might naturally suspect that the conditions of confinement would be a factor in curtailing or prolonging life, but all the functions seemed to proceed in so normal a manner that we have little reason to think that this is the case. Thus this material offers a very unusual opportunity of obtaining for this study an organism which passes through practically all of its development in its native habitat, unrestrained, and may finish its feeding and then may be brought together from various regions in the experimentor's laboratory. Many animals do not have this clearly defined boundary between adolescence and adulthood.

The groups of material used are as follows:[4]

		Year	Insects
Philosamia cynthia	Philadelphia	1913	208
Philosamia cynthia	New York	1913	151
Telea polyphemus	New York	1912	35
Telea polyphemus	St. Louis	1913	92
Telea polyphemus	Augusta, Ga.	1913	351
Telea polyphemus	Fall River, Mass.	1913	174
Telea polyphemus	Augusta (cellar)	1913	66
Callosamia promethea	Fall River, Mass.	1913	104
Samia Californica	Sonoma Co., Cal.	1912	12
Samia cecropia	River des Pêres (normal)	1913	220
Samia cecropia	River des Pêres (fluffy)	1913	74
Samia cecropia	South St. Louis	1913	142
Samia cecropia	New York	1913	110
Samia cecropia	Fall River, Mass.	1913	9
Samia cecropia	River des Pêres (cellar)	1913	42
Samia cecropia	South St. Louis (cellar)	1913	38
Samia cecropia	River des Pêres (house)	1912	69

These notes on longevity then were made on 17 lots of material comprising 1897 individuals. In addition to this, observations were made upon reproductive phenomena in their relation to longevity.

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[4] This material was obtained from Mr. J. J. Wirz of Augusta, Ga., Mr. Norman S. Easton of Fall River, Mass., Mr. Jesse Lund of New York City, and Mr. George H. Hosenfeld of St. Louis.

Longevity.

In 1910-11, observations were made on the longevity of about 900 of these moths, and the mean duration of life of the different lots were assembled in Table 1 (*loc. cit.,* p. 183). In the present work more than twice this number were employed in the continued search for new factors influencing the length of life. In like manner we have brought together in the table below the means for all of the lots of material herein considered. This table will frequently be referred to. (See Table 1.)

PHILOSAMIA CYNTHIA.

Two lots of Cynthia cocoons were obtained for this purpose, one lot from Philadelphia, which yielded 208 insects, and the other from New York City, which gave forth 151 adults in good condition for these observations. Table 2 below gives the details of the duration of life of the Philadelphia lot. The cocoons were shipped to St. Louis during the winter and kept out of doors until spring when they emerged between June 7 and 28. (See Table 2.)

Table 3 presents the details of the longevity of the New York lot. The cocoons arrived here during the winter, were likewise kept out of doors in the trees until spring, and 151 imagines emerged between May 30 and June 25. (See Table 3.)

In comparing Tables 2 and 3 we find the New York lot to be slightly the longer lived throughout. In these two tables we find practically no difference between the mated and unmated males, showing that here at least mating does not perceptibly alter the life of the male. Among the females, however, the unmated individuals lived longer than the mated ones. A comparison of all males with all females shows the females as a class to be longer lived.

TABLE 1.

Mean Duration of Life.

See Table	Lot	Year	Mated ♂'s	Unmated ♂'s	Mated ♀'s	Unmated ♀'s	All Mated Insects	All Unmated Insects	All ♂'s	All ♀'s	Whole Population
2	P. cynthia, Phila.	1913	5.56	5.56	6.72	7.16	6.12	5.97	5.56	6.86	6.53
3	P. cynthia, N. Y.	1913	6.61	6.59	7.20	7.48	6.90	7.04	6.60	7.37	6.99
4	T. polyphemus, St. L.	1913	....	8.70	....	10.51	....	....	8.70	10.51	9.59
5	T. polyphemus, N. Y.	1912	....	7.44	....	10.33	....	....	7.44	10.33	8.43
6	T. polyphemus, Augusta, Ga.	1913	8.33	8.05	6.00	10.24	7.55	9.07	8.06	10.02	9.03
7	T. polyphemus, Fall River, Mass.	1913	....	7.03	....	8.37	....	....	7.03	8.37	7.63
8	C. promethea, Fall River, Mass.	1913	....	5.47	7.00	8.13	....	....	5.47	8.04	6.73
9	S. Californica, California	1912	8.67	8.67	8.25	10.00	8.43	9.20	8.67	8.84	8.75
10	S. cecropia, River des Peres, St. L.	1913	10.59	9.45	8.90	10.29	9.73	9.90	9.77	9.93	9.86
11	S. cecropia, St. L. (fluffy)	1913	11.11	11.76	9.53	10.22	10.34	11.05	11.46	9.89	10.72
12	S. cecropia, South St. L.	1913	9.89	9.31	8.11	9.95	8.99	9.68	9.63	9.06	9.32
13	S. cecropia, N. Y.	1913	10.75	10.48	9.25	10.25	10.06	10.41	10.59	9.65	10.24
14	S. cecropia, Fall River, Mass.	1913	....	7.00	....	7.00	....	....	7.00	7.00	7.00
15	S. cecropia, River des Peres (cellar)	1913	....	14.78	....	10.83	....	....	14.78	10.83	12.52
16	S. cecropia, South St. L. (cellar)	1913	....	12.69	....	11.77	....	....	12.69	11.77	12.16
17	T. polyphemus, Augusta, Ga. (cellar)	1913	....	11.69	....	12.94	....	....	11.69	12.94	12.33
18	S. cecropia, River des Peres (house)	1912	....	14.85	....	16.96	....	....	14.85	16.96	15.74

TABLE 2.

P. cynthia. *Philadelphia, Pa., 1913.*

Class	Days									Total	Mean
	3	4	5	6	7	8	9	10	11		
Mated ♂'s	..	6	30	9	7	5	..	..	..	57	5.56
Unmated ♂'s	1	22	12	16	15	6	..	..	..	72	5.56
Mated ♀'s	..	1	7	17	14	11	4	..	..	54	6.72
Unmated ♀'s	1	1	1	5	6	6	4	..	1	25	7.16
All Mated Insects	..	7	37	26	21	16	4	..	..	111	6.12
All Unmated Insects	2	23	13	21	21	12	4	..	1	97	5.97
All ♂'s	1	28	42	25	22	11	..	..	..	129	5.56
All ♀'s	1	2	8	22	20	17	8	..	1	79	6.86
Whole Population	2	30	50	47	42	28	8	..	1	208	6.53

TABLE 3.

P. cynthia. *New York, 1913.*

Class	Days													Total	Mean
	3	4	5	6	7	8	9	10	11	12	13	14	15		
Mated ♂'s	..	1	8	7	4	8	3	..	..	..	..	..	..	31	6.61
Unmated ♂'s	2	7	8	3	8	6	7	2	1	..	..	..	..	44	6.59
Mated ♀'s	..	..	3	7	11	5	3	..	..	..	..	..	1	30	7.20
Unmated ♀'s	..	..	4	14	10	8	4	1	3	1	..	..	1	46	7.48
All Mated Insects	..	1	11	14	15	13	6	..	..	..	..	..	1	61	6.90
All Unmated Insects	2	7	12	17	18	14	11	3	4	1	..	..	1	90	7.04
All ♂'s	2	8	16	10	12	14	10	2	1	..	..	..	..	75	6.60
All ♀'s	..	..	7	21	21	13	7	1	3	1	..	..	2	76	7.37
Whole Population	2	8	23	31	33	27	17	3	4	1	..	..	2	151	6.99

TELEA POLYPHEMUS.

In 1911 observations were made on 19 moths of this species from St. Louis. These all remained unmated. The females exceeded the males in length of life by almost 4 days. This year we have material of this species in larger numbers and from four localities, St. Louis, New York, Augusta, Ga., and Fall River, Mass. So much similarity exists in these that it will be well to present the four tables together for ready comparison. (See Tables 4, 5, 6 and 7.)

It is to be regretted that the Polyphemus material from every locality could not be induced to mate in sufficient numbers to be of any value. Every precaution was taken to offer them one or many mates of various ages, but despite this we succeeded in getting longevity data on only 9 mated moths out of a total of 718 insects.

The cocoons were in all cases shipped to St. Louis during the winter months. The St. Louis, New York and Massachusetts lots were kept out of doors exposed to the normal weather conditions of St. Louis until almost the time when they were expected to emerge. The Georgia cocoons were allowed to remain in the house, in an upstairs room of varying temperature but unheated for the most part.

Some variation occurred in the dates of emergence of the different lots. Those from St. Louis emerged between April 24 and May 15; those from New York, May 17-30; from Georgia, May 2-June 28, and from Massachusetts, May 1-June 25. We shall not presume here to explain the causes of these differences, but we shall only say that they must carry some significance in showing that the date of emergence is not wholly dependent upon environmental conditions at the time of emerging, for these four lots were all under the same conditions at that time, but that the larval conditions must in some way

TABLE 4.

T. polyphemus. *St. Louis, Mo., 1913.*

Class	Days												Total	Mean
	5	6	7	8	9	10	11	12	13	14	15	16		
Unmated ♂'s	4	4	7	11	5	4	5	4	2	1	..	..	47	8.70
Unmated ♀'s	1	4	1	6	7	3	4	7	3	7	1	1	45	10.51
Whole Population	5	8	8	17	12	7	9	11	5	8	1	1	92	9.59

TABLE 5.

T. polyphemus. *New York, 1912.*

Class	Days											Total	Mean
	4	5	6	7	8	9	10	11	12	13	14		
Unmated ♂'s	1	7	1	3	3	3	2	2	1	..	..	23	7.44
Unmated ♀'s	..	1	..	1	1	1	1	2	3	1	1	12	10.33
Whole Population	1	8	1	4	4	4	3	4	4	1	1	35	8.43

TABLE 6.

T. polyphemus. Augusta, Ga., 1913.

Class	Days																Total	Mean
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Mated ♂'s	..	..	..	1	1	2	1	..	..	..	..	..	..	..	..	1	6	8.33
Unmated ♂'s	1	5	8	13	24	23	24	35	23	14	9	1	3	..	..	..	183	8.05
Mated ♀'s	..	..	..	2	..	..	1	..	..	..	..	..	..	..	..	..	3	6.00
Unmated ♀'s	..	2	4	3	4	8	19	21	24	19	23	15	8	6	3	..	159	10.24
All Mated Insects	..	..	..	3	1	2	2	..	..	..	..	..	..	..	..	1	9	7.55
All Unmated Insects	1	7	12	16	28	31	43	56	47	33	32	16	11	6	3	..	342	9.07
All ♂'s	1	5	8	14	25	25	25	35	23	14	9	1	3	..	..	1	189	8.06
All ♀'s	..	2	4	5	4	8	20	21	24	19	23	15	8	6	3	..	162	10.02
Whole Population	1	7	12	19	29	33	45	56	47	33	32	16	11	6	3	1	351	9.03

TABLE 7.

T. polyphemus. Fall River, Mass., 1913.

Class	Days													Total	Mean
	3	4	5	6	7	8	9	10	11	12	13	14	15		
Unmated ♂'s	1	5	16	19	25	9	9	7	2	2	..	1	..	96	7.03
Unmated ♀'s	3	1	7	8	12	14	7	9	7	5	..	4	1	78	8.37
Whole Population	4	6	23	27	37	23	16	16	9	7	..	5	1	174	7.63

contribute something toward determining the duration of pupal life.

In Polyphemus, the two southern localities yielded material of longer life than the two northern ones. May not this be considered a natural consequence of the animals having favorable conditions of growth and abundant supply of food in their developmental stages? Or should it be considered an indication that up north the tendency is toward going through the life cycle and reproduction in a lessened period?

Comparing now the tabulated summaries of the data on these four lots of Polyphemus from as many widely remote localities, we find that in absolutely every case the mean duration of life in the unmated females exceeds that of the males by 1.34 to 2.89 days. We must realize, of course, that every hour counts much in the life of one of these frail creatures, and that even this brief time represents approximately 20% of their normal lifetime. We may well disregard the 9 mated individuals in the Georgia lot, since their number is inadequate to be reliable for any conclusions.

It does indeed set one a-searching for reasons and explanations—to find that this condition of greater life of the female should exist in *every* lot of this material, each lot from a region far remote from the other, but this condition or character must exist in Polyphemus' nature, and must be a specific part of them as much as any anatomical character. We feel that these conclusions may be considered reliable, since they are based upon the evidence from so great a number of insects.

In comparing the mean duration of life of the entire population of these five lots, we find some divergence, in fact, great divergence when we consider what time means to these creatures. The St. Louis 1913 Polyphemus were the longest lived, with the mean for the whole population at 9.59 days. The Augusta material ranked next with a mean duration at 9.03 days; the New York

followed with a like mean of 8.43 days and the Fall River lot brought the lowest mean of 7.63 days.

This divergence invites investigation. Does the climate under which the larva lives, or the food supply, or the shorter or longer period in the larval stage (due to approaching cold or diminishing food supply), do any or all of these things affect the adult life? All of the animals had fed in their native haunts; all had passed through the entire formative period of their lives under unrestricted, natural conditions of their own habitat; when they came to us they were in the quiescent stage, waiting for the warm days of spring to emerge; nourishment could no longer be a factor in their lives. If the St. Louis climate affected the strangers in so marked a degree, why were not all affected alike?

This points to new fields of investigation. Herein lies excellent opportunity for ascertaining the causes of lengthened or shortened adult life; whether it be a specific trait or in how far it is merely the result of individual environment; and, if a specific character, whether it can be made to vary as such or can be permanently altered for the race by artificial conditions. It would be well if such work could be done from year to year, at localities remote from one another, individual records in large numbers accumulated, the place mode found and these compared with the climatic and other conditions.

CALLOSAMIA PROMETHEA.

In 1911 we obtained notes on the longevity of 170 insects of this species from the Crêve Coeur region, St. Louis. Here we found that the unmated males lived longer than the mated males, and likewise the unmated females exceeded the mated females, and that the females, all taken together as a class, lived longer than the males.

In a lot of cocoons of this species received from Fall River in 1913, 104 insects emerged between May 19 and

June 17, all of which were used in this investigation. (See Table 8.)

The table shows that they were extremely reticent about mating in confinement. All our efforts to offer the best opportunities brought successful results in the case of only four females, and even these rejected the males of their own species and mated with Cynthias. This table also shows that the unmated females were much longer lived than the males and also than the mated females, just as they were in the 1911 material, but as a whole the duration of life was much greater in the 1913 Fall River material than in the 1911 Crêve Coeur lot. Comparing in greater detail these two lots from different localities and years, we find the mean for the males to be greater in the former lot by 1½ days, and for the females by an excess of 2 days. Only consider the meaning of 2 days in the life of an insect, the duration of whose life is from 2 to 12 days.

It is indeed perplexing when we find that the Polyphemus from Massachusetts showed a mean much lower than did those from St. Louis, and that the Prometheas from there had a mean duration much greater than those from this region.

SAMIA CALIFORNICA.

Out of a large number of cocoons from Sonoma Co., California, only 14 insects emerged. Of these, 12 could be used for longevity work. (See Table 9.)

The table shows that they lived from 7 to 12 days, the mean for the entire population being 8.75 days. It is much regretted that the number available for this study is insufficient for the much desired comparisons, although it is interesting to note that these few give evidence of the same tendencies as the other species thus far considered in that the female sex and the unmated condition both tended toward longer life.

TABLE 8.

C. promethea. *Fall River, Mass., 1913.*

Class	Days											Total	Mean
	2	3	4	5	6	7	8	9	10	11	12		
Unmated ♂'s	1	4	12	12	10	7	5	1	1	..	..	53	5.47
Unmated ♀'s	..	..	..	8	8	3	4	9	8	4	3	47	8.13
Mated ♀'s	..	..	..	1	1	..	1	1	..	..	..	4	7.00
All ♀'s	..	..	..	9	9	3	5	10	8	4	3	51	8.04
Whole Population	1	4	12	21	19	10	10	11	9	4	3	104	6.73

TABLE 9.

S. Californica. *Sonoma Co., Cal., 1912*

Class	Days						Total	Mean
	7	8	9	10	11	12		
Mated ♂'s	2	...	...	...	...	1	3	8.67
Unmated ♂'s	1	...	1	1	...	...	3	8.67
Mated ♀'s	1	1	2	...	...	...	4	8.25
Unmated ♀'s	...	...	...	2	...	...	2	10.00
All Mated Insects	3	1	2	...	...	1	7	8.43
All Unmated Insects	1	...	1	3	...	...	5	9.20
All ♂'s	3	...	1	1	...	1	6	8.67
All ♀'s	1	1	2	2	...	...	6	8.84
Whole Population	4	1	3	3	...	1	12	8.75

SAMIA CECROPIA.

In the paper already referred to we paid most attention to the Cecropia moth, chiefly because this species could be procured in greatest numbers. In this paper we deal with five additional lots of this material under normal conditions, and three lots (controls) which will be taken up in detail later. The five lots are as follows:

River des Pêres (St. Louis) normal cocoons.
River des Pêres fluffy cocoons.
South St. Louis cocoons.
New York cocoons.
Fall River cocoons.

Before going into the details of this work, it may be well to give a brief resumé of the previous experiments.

The River des Pêres Cecropia population emerging in the spring of 1910 split up into two distinct lots; all of the moths which emerged early, April 13 to May 14, lived long lives (the mean for this portion of the population was 16.65 days), while all of those which emerged late in the season, May 14 to June 17, lived short lives (the mean for this group being 10.14 days). In 1911 this splitting up did not occur, but the three lots of material known as the St. Louis Cecropias 1911, the New York Cecropias 1911, and the Incubator Cecropias 1911, gave a mean duration of life of 7.71 days, 8.06 and 8.00 days respectively. This gave a clue to the following hypothetical explanation. The 1910 material began to emerge in April, a month earlier than usual. This abnormally early emergence was perhaps due to the exceptionally warm month of March, and when the unusually cold weather followed in April the animals lived noticeably longer than usual. It was thought that the cold was directly responsible for this long life since they were numb and remained quite inactive, and hence expended little or none of their reserve energy, and that those moths which emerged later found the weather warm and

inviting to activity, and in due time expended their quota of stored nourishment and died after the normal length of life. Further experiments, keeping adult moths in an ice-box, proved that cold markedly lengthens their life.

We have then already stated that the mean duration of life of the Cecropia moth was shorter in 1911 than in 1910; this may be correlated with the fact that the period in which they lived was warmer in 1911. A comparison of Table 8 with Table 1 (*loc. cit.*, pp. 192 and 183), shows that in every case a variation in the length of life accords with a simultaneous variation in temperature.

Now we come to the data of the 1913 Cecropia work. The St. Louis Cecropias known as the River des Pêres lot were gathered from the same area, near Forest Park, as in previous years. This time they were sorted into two lots, one containing all of the normal cocoons, and the other the loosely woven or fluffy cocoons.[5] 336 insects emerged from the normal cocoons between May 9 and June 16, 220 of which were used for longevity data. (See Table 10.)

Here again the mean duration of life was greater for the mated males than the unmated males and *vice versa* for the females. To be sure the mean length of life is almost equal for the two classes, "all mated" and "all unmated" insects, and also the groups "all males" and "all females," but this equality is probably of little significance since it results merely from the counterbalancing of the more significant numbers just referred to. The mean length of life for this whole population was 9.86 days.

Of the 79 insects which emerged from the fluffy cocoons between May 5 and June 12, 74 were used for longevity notes. (See Table 11.)

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[5] These were sorted out and treated separately for the purpose of continuing the study (see Psyche, 18: 168-170, 1911) of this fluffy condition to ascertain whether it is hereditary, and whether other differences, such as longevity, oviposition, etc., make them distinctly different from normal cocooned insects.

TABLE 10.

S. cecropia. *St. Louis, River des Peres, 1913.*

Class	Days																				Total	Mean
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
Mated ♂'s	..	..	..	..	1	2	4	4	3	4	4	3	2	2	..	..	..	..	..	..	29	10.59
Unmated ♂'s	..	..	1	6	2	9	7	13	12	12	4	4	1	3	1	..	..	..	..	..	75	9.45
Mated ♀'s	..	..	..	..	5	5	4	7	2	3	3	..	..	..	..	..	1	..	..	..	30	8.90
Unmated ♀'s	1	3	..	3	4	10	3	12	7	9	12	5	6	9	..	1	..	..	..	1	86	10.29
All Mated Insects	..	..	..	..	6	7	8	11	5	7	7	3	2	2	..	..	1	..	..	..	59	9.73
All Unmated Insects	1	3	1	9	6	19	10	25	19	21	16	9	7	12	1	1	..	..	..	1	161	9.90
All ♂'s	..	..	1	6	3	11	11	17	15	16	8	7	3	5	1	..	..	..	..	..	104	9.77
All ♀'s	1	3	..	3	9	15	7	19	9	12	15	5	6	9	..	1	1	..	..	1	116	9.93
Whole Population	1	3	1	9	12	26	18	36	24	28	23	12	9	14	1	1	1	..	..	1	220	9.86

TABLE 11.

S. cecropia. *St. Louis, River des Peres, 1913, (fluffy).*

Class	Days																	Total	Mean
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20		
Mated ♂'s	1	..	..	2	2	..	..	2	1	1	5	..	2	1	1	..	..	18	11.11
Unmated ♂'s	..	..	..	1	1	1	..	2	7	2	3	..	1	2	..	..	1	21	11.76
Mated ♀'s	1	..	1	..	3	..	3	3	4	..	..	1	..	..	..	1	..	17	9.53
Unmated ♀'s	1	..	1	..	1	2	2	3	2	1	1	2	2	..	..	..	..	18	10.22
All Mated Insects	2	..	1	2	5	..	3	5	5	1	5	1	2	1	1	1	..	35	10.34
All Unmated Insects	1	..	1	1	2	3	2	5	9	3	4	2	3	2	..	..	1	39	11.05
All ♂'s	1	..	..	3	3	1	..	4	8	3	8	..	3	3	1	..	1	39	11.46
All ♀'s	2	..	2	..	4	2	5	6	6	1	1	3	2	..	..	1	..	35	9.89
Whole Population	3	..	2	3	7	3	5	10	14	4	9	3	5	3	1	1	1	74	10.72

In this table we see only a slight difference in the mean duration of life of the mated and unmated males, and in this case it is in favor of the unmated individuals; the same is true of the females. When we compare the mean for all females with that of all males, we are surprised to find a much greater difference, and strangely enough, this is in favor of the males. The mean duration of life for this entire lot coming from fluffy cocoons is 10.72 days, or nearly a day more than the normal moths of the same year and place. (See Table 10.) When we compare the figures for these two parts of the population, we see that the mean length of life is greater in the fluffy lot in practically every class. Why should it be so unless the insects in the large, fluffy cocoons are endowed with greater vigor or a greater supply of reserve energy which carries them just a little further in life? May it be that they are thus well supplied with reserve nutriment as a direct result of abundant food supply of these individuals in the larval stage, and that the spinning of the larger cocoons is likewise merely the outcome of this accelerated growth?

Our next lot of material is that known as the South St. Louis Cecropias. Of the 236 insects which emerged from these cocoons between May 7 and June 13, 142 furnished longevity data. (See Table 12.)

Here we find that the mean duration of life of the mated males was greater than that of the unmated ones, while just the reverse was true for the females, and here too the mean duration of life of all males taken together was greater than that of all females. The mean for the whole population, 9.32 days, is the lowest of the Cecropia lots taken up in this paper, but it is greater than some of the 1911 lots.

The New York Cecropia material consisted of 143 insects which emerged between May 1 and June 4, 110 of which were used for these tabulations. (See Table 13.)

In this group we find precisely the same relation of length of life to sex and mating as in the foregoing lot;

TABLE 12.

S. cecropia. *South St. Louis, 1913.*

Class	Days																	Total	Mean
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Mated ♂'s	1	..	1	..	1	1	4	5	12	2	6	1	..	..	1	1	..	36	9.89
Unmated ♂'s	..	..	..	3	..	3	6	3	6	5	1	..	1	..	..	..	1	29	9.31
Mated ♀'s	..	..	3	1	3	7	8	5	5	3	2	..	..	..	..	..	..	37	8.11
Unmated ♀'s	1	..	..	2	4	..	3	7	5	5	6	4	2	..	..	..	1	40	9.95
All Mated Insects	1	..	4	1	4	8	12	10	17	5	8	1	..	..	1	1	..	73	8.99
All Unmated Insects	1	..	..	5	4	3	9	10	11	10	7	4	3	..	..	..	2	69	9.68
All ♂'s	1	..	1	3	1	4	10	8	18	7	7	1	1	..	1	1	1	65	9.63
All ♀'s	1	..	3	3	7	7	11	12	10	8	8	4	2	..	..	..	1	77	9.06
Whole Population	2	..	4	6	8	11	21	20	28	15	15	5	3	..	1	1	2	142	9.32

TABLE 13.

S. cecropia. *New York, 1913.*

Class	Days											Total	Mean
	5	6	7	8	9	10	11	12	13	14	15		
Mated ♂'s	..	1	1	3	2	6	2	7	4	2	..	28	10.75
Unmated ♂'s	1	1	3	..	8	10	5	6	5	1	2	42	10.48
Mated ♀'s	..	..	4	5	7	3	2	1	1	1	..	24	9.25
Unmated ♀'s	..	1	3	2	2	..	1	3	2	..	2	16	10.25
All Mated Insects	..	1	5	8	9	9	4	8	5	3	..	52	10.06
All Unmated Insects	1	2	6	2	10	10	6	9	7	1	4	58	10.41
All ♂'s	1	2	4	3	10	16	7	13	9	3	2	70	10.59
All ♀'s	..	1	7	7	9	3	3	4	3	1	2	40	9.65
Whole Population	1	3	11	10	19	19	10	17	12	4	4	110	10.24

TABLE 14.

S. cecropia. *Fall River, Mass., 1913.*

Class	Days								Total	Mean
	3	4	5	6	7	8	9	10		
Unmated ♂'s	..	1	..	1	1	1	..	1	5	7.00
Unmated ♀'s	..	1	..	1	..	1	..	1	4	7.00
Whole Population	..	2	..	2	1	2	..	2	9	7.00

in the males, the mated individuals survived longer and in the females the unmated ones. And again in comparing all males with all females we find the greater mean longevity in favor of the males.

The mean for the entire population is 10.24 days. This is greater than that of any other lot of Cecropias of this year excepting those from fluffy cocoons. Of course the length of life does not equal that of the lot in 1910 which emerged early and lived so much longer than usual on account of the peculiar weather conditions. It is very interesting to note that the mean longevity for this entire lot is much higher than that of the same species from the same locality only two years before (*loc. cit.*, p. 193). Inspection of these tables will show that in every case the mean duration was greater for the 1913 New York Cecropias by from 2 to 3 days.

From the Fall River lot of Cecropia cocoons only 9 moths were obtained. This material is insufficient to warrant comparisons. (See Table 14.)

DISCUSSION OF LONGEVITY.

To briefly summarize all of the Cecropia data in a comparative way, we should bring together the details of Table 1 of this paper with Table 1 of the former publication.

First we see that none of the Cecropia excepting the 1910 lot split up into distinct groups of early and late emerging, and long- and short-lived individuals. The reason why this phenomenon should stand alone and unrepeated in the subsequent collections was the unique weather conditions of that year, giving the extremely favorable climatic conditions in March, hastening their development to an early emergence, followed by an unusually cold April which caused them to live longer. But when we compare the means for the whole population of Cecropia moths in the various lots (see last column of

the tables), we find considerable variation, but all within the limits of 7.71 and 10.72 days.

What can be the cause of this variation in the length of life? Why, for instance, should the New York Cecropias show a mean life for the whole population in 1911 of 8.06 days, and in 1913 of 10.24 days? The difference may seem trivial in itself, but it is significant enough to assure us that there must be some potent factors, as yet undiscovered, working singly or together determining these conditions. How can we account for it unless it be that one crop of insects acquire more or another less food as larvae, or perhaps the succulence or the chemical composition of the food plants may vary from year to year, or a thousand fine adjustments in nature of which we are yet ignorant.

Comparing next the mean length of life of all males and all females, we find in two lots the duration of life of both sexes almost equal, and in seven lots[6] we find the mean for the males to be the greater. This shows that the male lives as long or even longer than the female. This is in direct contrast with what we have already observed in Polyphemus, where the male is much shorter lived.

Then again when we compare the means for all mated insects of both sexes with all unmated, we find that for every one of the nine lots the life was longer in the unmated groups, but which sex contributes most to this higher mean can be ascertained by inspecting the first four columns of the two tables. In considering the length of life of the mated and unmated males we find that in 8 of the 9 lots of Cecropias the mean duration of life was practically equal for the mated and unmated males. In only one case, the 1913 St. Louis Cecropias, do we find the life longer for the mated males, by a difference of 1.14 days. Thus we see that in this species copulation hardly

[6] Excluding the Fall River cecropias, which were insufficient in numbers to be reliable, and the ice-box cecropies, which were under artificial conditions.

affects the longevity of the male one way or the other, and hence we see that in the above discussion of the duration of life of all mated insects as compared with all unmated insects that the males contribute nothing, or at least very little, to the figures showing the unmated insects to be the longer lived. The responsibility of this significant difference must therefore devolve upon the females—a very worthy point. So if the males do not cause this swinging of the balance, a survey of the tables ought to show that the unmated females are longer lived than the mated females. And so it does. In absolutely every case we find the mean duration of life of the groups of unmated females to be the greater by a good margin.

Here we come to the problem: is the longevity of the virgin female the natural length of life, and is it cut short by mating, or is the life of the mated female the natural one, and without mating is it prolonged, as one might think, to give the individual a chance to mate? But since we see the unmated Polyphemus living a long period, would it be far-fetched to conclude that in the mated condition of the Cecropia the life is shortened? But whether or not this shortening or lengthening of life is of advantage to the species we leave for later discussion.

Since the male can be a vagrant and take license as he will and not have his number of days reckoned for him, and since it seems that the female must pay the price of complete living by forfeiture of some days of her life, it would be of interest to know precisely how such factors react upon organisms higher in the scale of life, say rats, poultry, sheep, etc., and from there it would be only a step to our own species.

LONGEVITY AND TEMPERATURE.

In 1910 when we suspected that low temperature tended to prolong the life of the early emerging insects, we placed a number of Cecropias in an ice-box, the tem-

perature of which varied from 9° to 12° C. Here we found that they attained the surprising maximum age of 32 days, while their contemporaries in ordinary conditions reached only 13 days.

Again this year we attempted similar experiments, but not in so rigorous a form. The material (two lots of Cecropias and one of Polyphemus) was placed in a cemented basement where the temperature was somewhat lower than the out-of-doors, and also considerably lower than the room where the other live material was kept. The three tables following give the details of the work. (See Table 15.)

By comparing these 42 insects with their contemporaries, the River des Pêres Cecropias, we find the mean duration of life considerably greater for those kept in the basement, and especially the males of the lot. The mean for the entire basement lot is greater than that for those kept in the ordinary living-room by 2.66 days.

From the South St. Louis lot of Cecropias, 38 were selected at random and placed in the cool basement. (See Table 16.)

In this lot the mean for the males and also for the whole population is somewhat lower than that for the River des Pêres basement material—a condition parallel with the parent stock. But here too we have a higher mean duration of life than for their contemporaries in the living-room. We find the cellar conditions prolonging the life of these 2.84 days over that of their fellows.

Sixty-six Polyphemus moths, selected at random from the Atlanta, Ga., material were subjected to the same treatment. (See Table 17.)

When we compare these with their contemporaries in the living-room (Table 6), we are again reminded of "not how long but how well one lives"; again the laws of compensation are revealed. These lethargic animals in the cellar lived longer than did those in the living-room by differences far greater than those recorded for the Cecropias,—*viz.*, the unmated Polyphemus males lived 3.64

TABLE 15.

S. cecropia. *River des Peres, St. Louis, 1913, (cellar lot).*

Class	Days															Total	Mean
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Unmated ♂'s	..	..	1	..	1	1	1	1	1	..	2	3	3	1	3	18	14.78
Unmated ♀'s	1	1	..	..	3	7	4	4	2	..	1	..	..	..	1	24	10.83
Whole Population	1	1	1	..	4	8	5	5	3	..	3	3	3	1	4	42	12.52

TABLE 16.

S. cecropia. *South St. Louis, 1913, (cellar lot).*

Class	Days															Total	Mean
	3	4	5-6	7	8	9	10	11	12	13	14	15	16	17	18-23	24	
Unmated ♂'s	1	..	..	..	..	2	..	2	3	1	2	..	4	1	..	..	16	12.69
Unmated ♀'s	..	1	..	1	2	..	3	4	2	2	3	2	1	..	..	1	22	11.77
Whole Population	1	1	..	1	2	2	3	6	5	3	5	2	5	1	..	1	38	12.16

TABLE 17.

T. polyphemus. *Augusta, Ga., 1913, (cellar lot).*

Class	Days																	Total	Mean
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
Unmated (all) ♂'s	2	..	1	2	1	6	5	..	5	3	4	1	2	..	..	..	..	32	11.69
Unmated (all) ♀'s	..	..	3	2	4	1	3	5	1	3	1	3	5	..	1	..	2	34	12.94
Whole Population	2	..	4	4	5	7	8	5	6	6	5	4	7	..	1	..	2	66	12.33

TABLE 18.

S. cecropia. *House lot, 1912.*

Class	Days																															Total	Mean
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
Males	1	.	1	.	2	1	4	5	3	3	1	3	2	4	1	..	1	1	..	4	..	..	1	..	..	1	..	..	..	..	1	40	14.85
Females	.	1	2	.	.	1	3	..	2	3	2	..	3	1	..	..	..	2	1	..	1	1	..	1	..	1	..	1	2	1	..	29	16.96
Whole Population	1	1	3	.	2	2	7	5	5	6	3	3	5	5	1	..	1	3	1	4	1	1	1	1	..	2	..	1	2	1	1	69	15.74

days longer in the basement than did those in the living-room, the females 2.70 days longer, and the whole population 3.30 days longer than their more energetic fellows.

In January and February 69 adult Cecropias emerged from cocoons gathered from the River des Pêres region and kept in a living-room which was slightly heated during the day, but almost always cool at night. The table shows the duration of life of these insects. (See Table 18.)

Some lived but a very short time, due perhaps to abnormalities or weakness resulting from their premature development and emergence, but for the most part they gave results comparable with the ice-box experiments of 1910 (*loc. cit.*, p. 190), and while the mean duration of life is not so great in all of these three lots, yet we found the maximum duration of life to be even greater than in the ice-box work.

Since these various conditions of lower temperature prolonged the lives of the insects considerably, and since the extreme conditions of the ice-box prolonged them extremely, one cannot evade the conclusion that temperature is a factor which to a great extent controls the length of life of these delicate organisms. It may be only a matter of delicate, refined technique (slowly and gradually lowering the temperature, with proper ventilation, etc.), that is needed to suspend metabolism and increase the longevity in these frail creatures to surprising extremes, since it seems principally a matter of conservation of energy until it is necessary for such energy to be expended. Such phenomena undoubtedly occur in the Lepidoptera which hibernate as imagines.

Oviposition.

NUMBER OF EGGS CARRIED.

The moths of the family Saturniidae here considered hibernate as pupae in silky cocoons. The caterpillars, heavy consumers of vegetation, stop feeding at a certain

period of their growth and spin these cocoons about themselves. After a very brief period in the cocoons the larvae transform into pupae. It is in this pupal stage that the development of the eggs occurs. When a female emerges as an adult, Nature has already prepared her for her brief life by having all of the eggs matured and ready for oviposition. In some of the longer-lived Lepidoptera, some of the eggs are being deposited while others are maturing. Here, however, the eggs are all ready to be laid when the insect emerges from the cocoon, and when these are laid, or sometimes before all are deposited, she dies. With conditions such as these it is easy to tell precisely the total number of eggs carried by each individual.[7] Of course, we assume that the total number of eggs carried by each female is influenced by the home conditions of the larva, that is, food, climate and moisture, and that the local conditions of the last few months of pupal life, spent at St. Louis, could not in any way influence the number of its eggs.

During 1911-13 we made a study of the eggs carried by the 504 individuals of 19 lots of these moths. (See Table 19.)

For convenience the numbers of eggs carried were thrown into groups of twenty, but the averages in the last column were reckoned from the actual numbers. The table gives some interesting comparative details. For the five lots of Polyphemus material the means vary from 198 to 293 eggs. The mean number of eggs carried by the Fall River Polyphemus of 1913 equaled that of St. Louis for the same year. The St. Louis lot for 1911 had the largest average while the New York 1912 lot ranked second, but for the last two the numbers of observations were small, and one must be cautious not to lay too much weight upon this evidence. The Polyphemus from Augusta, Ga., had the smallest average number of eggs, 198.

[7] This is done by adding the number of ova deposited to the number retained as revealed by dissection after death.

TABLE 19.

The Number of Eggs Carried at Emerging.

Class	0- 20	21- 40	41- 60	61- 80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-240	241-260	261-280	281-300	301-320	321-340	341-360	361-380	381-400	401-420	421-440	441-460	Total	Mean
Polyphemus, St. L. 1911	..	..	..	..	..	..	..	..	..	..	..	..	1	1	2	1	2	..	..	..	..	..	..	7	293
Polyphemus, N. Y. 1912	..	..	..	..	1	..	1	1	..	1	..	..	1	2	2	..	2	1	..	..	..	..	..	12	245
Polyphemus, St. L. 1913	..	..	1	1	2	..	5	1	3	3	4	5	9	3	3	2	2	1	..	..	..	..	..	45	216
Polyphemus, Mass. 1913	..	..	..	1	..	3	1	5	3	5	5	3	6	2	1	2	3	1	..	1	..	..	..	42	218
Polyphemus, Ga. 1913	..	1	1	1	..	1	2	5	3	3	3	4	5	2	..	2	..	..	..	..	1	..	..	34	198
Cecropia, St. Louis .....[8]1910	..	..	..	..	..	..	..	..	..	..	2	..	6	4	3	8	8	5	9	4	1	8	6	64	344
Cecropia, St. Louis 1912	..	..	..	..	..	..	..	..	3	2	5	2	1	2	2	6	..	2	1	1	..	..	..	27	262
Cecropia, St. Louis 1913	..	..	..	..	..	..	..	3	1	2	..	2	3	4	4	5	2	2	3	1	1	..	1	34	285
Cecropia, St. L. (fluffy) 1913	..	..	..	..	..	..	..	..	2	..	1	..	1	..	1	4	1	2	1	3	1	1	2	20	332
Cecropia, South St. L. 1913	..	..	..	..	..	..	1	..	..	..	1	..	3	3	1	2	1	1	1	..	..	..	..	14	282
Cecropia, N. Y. 1913	..	..	..	..	..	..	..	2	..	..	1	1	2	1	2	5	3	1	2	..	1	..	..	21	290
Promethea, Creve Coeur.....1911	1	..	1	2	1	3	2	1	3	9	8	3	2	7	1	2	..	..	..	..	..	..	..	46	195
Promethea, Mass. 1913	..	..	..	2	1	2	3	6	5	1	6	3	2	2	1	..	..	1	..	1	..	..	..	36	190
Luna, St. L. 1911	..	2	..	4	2	..	..	..	1	1	..	..	..	..	..	..	1	..	..	..	..	..	..	11	111
Luna, Pike Co. 1911	..	..	..	1	..	..	2	1	1	..	1	2	1	1	1	..	1	..	..	..	..	..	..	12	203
Californica, Cal. 1912	..	..	..	..	..	..	..	..	..	..	..	1	2	..	1	1	..	..	..	..	..	..	..	5	266
Cynthia, N. Y. 1912	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	1	..	1	1	..	..	1	1	6	374
Cynthia, N. Y. 1913	..	..	..	..	..	..	..	..	..	2	2	3	5	3	4	4	6	4	4	2	2	3	..	44	312
Cynthia, Phila. 1913	..	..	..	..	..	..	..	..	..	1	1	2	..	1	1	1	3	6	4	3	1	..	..	24	327

[8] These data published in Trans. Acad. Sci., St. Louis, 20: 315-316, 1911.

One would think that the semi-tropical conditions of Georgia, with an abundance of vegetation through a longer feeding season than at St. Louis or Fall River, would stimulate the production of eggs far to exceed those from the northern localities.

In considering the six lots of Cecropia material we have not so wide a range in their means, 262 to 344 eggs. The River des Pêres lots alone show a fluctuation from year to year of 344, 262 and 285 eggs. It is interesting to note that the South St. Louis material gathered in 1913 from an area two or three miles distant from the River des Pêres region should show an average practically equal (282) for the same year, while the mean for the New York lot of that year also, 290, is strikingly similar.

The females from the large, fluffy cocoons culled from the 1913 River des Pêres lot show a much higher average number of eggs (332) than the normal stock, or than the Cecropias of any other place or year excepting the 1910 lot. This point, added to the fact of the greater length of life, certainly leaves one with the conviction that these animals are more favorably endowed than their fellows, and will increase more rapidly than the remainder of the population, if not checked by other factors.

We can hardly speculate upon the significance of these details. We do not know what influences are to be reckoned with in the determination of egg production. We must wait for experimental research to tell us whether the number of ova produced is in any way correlated with the nutrition of the animal during the developmental period.

The Prometheas from St. Louis in 1911 and those from Fall River in 1913 show but very little difference in the average number of eggs carried (195 and 190 respectively), despite the fact that the two localities are extremely remote.

The two small lots of Lunas, one from St. Louis and the other from Pike Co., Mo., differ widely in the mean number of eggs carried, but the small number of the St. Louis lot may be attributed to the fact that they were bred in confinement, probably with insufficient or improper food.

The material of *S. californica* is insufficient for comparison, but shows the mean number of ova produced is 266.

Among the Cynthias the New York 1912 lot shows the highest mean, 374, but this is for only 6 insects and is worth little in a comparative way, but the fact that these prolific females were all that emerged from about 300 cocoons shows the survival of the most vigorous, and that the number of ova is in a way a criterion of vigor.

We feel sure that further gathering of data on these species from the same localities at intervals of a few years, or for successive years, would show some interesting results. Cannot one detect the direction in which the changes are leading the species by a study of such important problems as fecundity or longevity from year to year, as well as by elaborate studies on some morphological detail?

COMPLETENESS OF OVIPOSITION.

We have just discussed the number of eggs carried by these moths. We shall now take up in detail the question of complete or incomplete oviposition of these masses in relation to the mated or unmated condition of the individual.

All or a considerable portion of the eggs are deposited during the life of the insect, regardless of whether or not mating occurs. We have ascertained the number of eggs deposited by each female, and found what per cent this is of the total number carried by her. The population was divided into two great classes, the mated and the unmated, and then tabulated according to the per cent

TABLE 20.

The Completeness of Oviposition of Mated and Unmated Insects.

Lot	Per Cent of Eggs Deposited by Each ♀											Total Individuals	Mean %	Max. No. of Eggs	Min. No. of Eggs
	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100				
Polyphemus, N. Y. 1912 .....U	....	....	....	....	....	....	....	1	....	5	5	11	87.7	327	89
Polyphemus, St. L. 1911.....U	....	....	....	....	....	1	....	1	....	....	5	7	83.6	321	116
Polyphemus, St. L. 1913.....U	....	....	....	....	2	1	1	1	....	9	29	43	87.3	335	23
Polyphemus, All .....U	....	....	....	....	2	2	1	2	....	9	34	50	86.8	....	....
Polyphemus, Fall River 1913.....U	1	....	....	1	....	....	....	....	....	6	34	42	89.6	382	0
Polyphemus, Ga. 1913.....U	1	....	1	....	2	1	....	1	1	5	22	34	81.9	403	0
Polyphemus, All combined .....U	2	....	1	1	4	3	1	4	1	25	95	137	86.5	....	....
Cynthia, N. Y. 1913.....M	....	....	....	....	3	2	2	1	3	4	12	27	76.9	423	63
Cynthia, N. Y. 1913.....U	1	7	4	....	1	1	1	1	....	1	....	17	22.4	230	0
Cynthia, N. Y. 1912.....U	....	....	....	....	....	1	1	3	1	....	....	6	61.6	320	167
Cynthia, Phila. 1913.....U	....	3	....	....	....	....	....	....	1	....	....	4	22.5	201	6
Cynthia, Phila. 1913.....M	....	1	1	3	1	3	1	2	2	2	4	20	57.5	329	30
Cynthia, All .....U	1	10	4	....	1	2	2	4	2	1	....	27	31.1	....	....
Cynthia, All .....M	....	1	1	3	4	5	3	3	5	6	16	47	68.6	....	....
Cecropia, N. Y. 1913.....U	....	....	....	....	1	....	....	....	....	1	2	4	77.5	302	140
Cecropia, N. Y. 1913.....M	....	....	....	....	1	3	....	....	1	1	11	17	80.9	403	83
Cecropia, St. L. 1913.....M	....	....	2	....	....	2	....	....	4	8	17	33	82.3	388	49
Cecropia, St. L. 1913.....U	....	....	....	1	....	3	....	3	....	3	5	15	72.3	441	72
Cecropia, St. L. 1913 (fluffy).....M	....	....	....	....	....	1	2	1	....	1	8	13	81.9	442	78
Cecropia, St. L. 1913 (fluffy).....U	....	....	....	2	....	....	2	....	1	1	1	7	59.3	360	67
Cecropia, All (fluffy).....	....	....	....	2	....	1	4	1	1	2	9	20	74.	....	....
Cecropia, All .....M	....	....	2	....	1	6	2	1	5	10	36	63	81.8	....	....
Cecropia, All .....U	....	....	....	3	1	3	2	3	1	5	8	26	69.6	....	....
Luna, St. L. 1911.....U	....	....	....	....	....	....	1	....	....	2	8	11	89.5	323	2
Luna, Pike Co. .....M	....	....	....	....	....	....	....	....	....	....	4	4	95.	226	121
Luna, Pike Co. .....U	....	....	....	....	1	....	....	....	....	1	6	8	86.2	321	62
Luna, All combined	....	....	....	....	1	....	1	....	....	3	18	23	89.3	....	....
Californica, Cal. 1912 .....M	....	....	....	....	....	....	....	....	....	....	2	2	95.	297	296
Californica, Cal., 1912 .....U	....	....	....	....	....	....	1	1	....	....	....	2	60.	161	138
Promethea, Mass. 1913.....U	....	....	1	1	4	3	....	1	7	7	12	36	73.3	394	19
Promethea, Creve Coeur 1911.....U	....	....	....	1	2	4	1	2	3	6	5	24	69.6	237	8
Promethea, Creve Coeur 1911.....M	....	....	....	2	1	....	1	2	2	6	8	22	76.8	277	26
Promethea, All combined .....U	....	....	1	2	6	7	1	3	10	13	17	60	71.8	....	....

of their eggs deposited. During 1911-12-13, the details of oviposition were recorded for 409 insects of the 24 lots as enumerated in table 20.[9]

Inspection of these figures shows that the mean percentage of oviposition in Polyphemus varies from 81.9 to 89.6%. There is only a slight difference in the mean per cents in the two lots from St. Louis, while a far more pronounced difference is at once apparent between the Fall River, Mass., and the Augusta, Ga., lots. Perceiving that the mean per cent for all polyphemus combined is 86.5, and that 95 females of the 137 deposited from 91 to 100% of their eggs, we must conclude that as a whole Polyphemus, even unfertilized, oviposit almost perfectly.

In the Cynthias we have two lots, one from New York and one from Philadelphia, but here we have notes based on the mated and unmated condition, and the effects of this factor are at once apparent. In the New York 1913 lot the mated ones give a mean per cent of oviposition of 76.9, while the unmated females give only 22.4%. To be sure the unmated females of the 1912 lot give a mean per cent of oviposition of 61.6, but these were the vigorous individuals already referred to which survived out of 300 cocoons. The Philadelphia material showed practically the same relation as the first; the mated insects deposited 57.5% of their eggs and the unmated ones only 22.5%.

The data for *S. cecropia* are self-explanatory, but we may call attention to the fact that here again the percents for the unmated insects were somewhat lower, while the Cecropias all taken together did not show such a well-perfected ability completely to oviposit as did the

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[9] For instance, on the first line we read: *Telea polyphemus*, from New York, emerged 1912, and all remained unmated; 1 insect deposited from 61 to 70% of the total number of eggs she carried, 5 of them 81 to 90%, and 5 of them 91 to 100%; total, 11 insects. The mean per cent deposited by the whole population of 11 females was 87.7%, while the maximum actual number of eggs deposited by any individual of the lot was 327 and the minimum 89.

Polyphemus. When all of the lots of Cecropias are taken together, we find that copulation increases the percentage of oviposition by 12%.

Our Luna moths showed a high percentage of oviposition, 95% for the mated moths and 89.5 and 86.2% for the unmated St. Louis and Pike Co., respectively.

Our data on *S. californica,* although very insufficient, shows precisely the same tendencies as in the other species, the mated insects depositing 95% of their eggs, while the unmated moths reached only 60%. The Prometheas also give evidence of this tendency, but with a lower percentage of oviposition.

AGE WHEN FIRST EGGS WERE DEPOSITED.

We have elsewhere stated that mating is not the necessary precedent of oviposition, although it has become apparent in the preceding chapters that that function exerts some influence upon egg-laying. So it is not unusual that we at first thought perhaps the unfertilized females "held off egg-laying in the hope" of mating, and that if mating did not occur before late in life the ovipositing then commenced without it. With this question in mind we have compiled a table showing at what age 142 unfertilized females began to oviposit. (See Table 21.)

It will be noted that in no instance did oviposition begin after 7 days of age, nor on the first day[10] of the insect's life. 29% of the moths commenced ovipositing on the second day of their life, 40% on the third day, 19% on the fourth day and the remaining 12% of the insects began at the age of 5, 6 or 7 days to oviposit. This shows clearly that oviposition begins in due time, despite the fact that such oviposition is of no use for the propagation of the species, but that by conserving this ma-

[10] The first day of an insect's life is the same day wherein it emerged, but it may have emerged late in the day and hence its first day may consist of only a few hours.

TABLE 21.

Age When First Eggs Were Deposited.

Lot	Age—Days							Total
	1	2	3	4	5	6	7	
Promethea, St. L.....1911	..	2	8	9	5	4	..	28
Luna, St. L. 1911	..	1	7	1	2	..	..	11
Luna, Pike Co. 1911	..	..	4	4	1	..	..	9
Cynthia, N. Y. 1912	..	2	4	..	..	..	..	6
Polyphemus, St. L.....1911	..	1	5	1	..	..	..	7
Polyphemus, N. Y.....1912	..	7	4	..	..	..	..	11
Polyphemus, Ga. 1913	..	4	4	1	1	1	..	11
Polyphemus, St. L. 1913	..	18	11	8	1	..	1	39
Polyphemus, Fall River 1913	..	5	10	3	2	..	..	20
Total	..	40	57	27	12	5	1	142

terial until after mating much would be gained and nothing lost, since, as the foregoing discussions have shown, oviposition is more complete after mating than without it in spite of the expenditure of a comparatively long time for copulation.

In 1912 some Cecropia, kept in a living-room at the ordinary temperature, emerged in February and March. After emerging they were subjected to varying degrees of temperature. It was noticed that oviposition in these insects commenced much later than usual in life. We have previously recorded that unmated females of this species (these were unmated) usually oviposit on the second or third day after leaving the cocoon. Under these abnormal conditions these 19 insects first oviposited on the following days of age:

18 days..... 2 individuals.
17 days..... 1 individual.
15 days..... 3 individuals.
14 days..... 2 individuals.
13 days..... 2 individuals.
8 days..... 1 individual.
6 days..... 4 individuals.
5 days..... 2 individuals.
4 days..... 2 individuals.

No like tabulations are offered for the age of earliest oviposition of mated females, because even when the opportunity lay before the females to mate as early in life as they pleased, some ova were often deposited before copulation, and if not, oviposition was merely delayed until the conclusion of the mating period.

AGE AT WHICH THE GREATEST NUMBER OF EGGS WERE DEPOSITED.

In connection with the observations on the age at which the females begin to oviposit, it was thought desirable to find out at what age most of the eggs are deposited. This will give us an idea of the extent of the waste due to the oviposition which occurs too early for mating.

TABLE 22.

Age at Which the Greatest Number of Eggs Were Deposited.
(Unmated Insects.)

Lot	Age—Days.												Total
	2	3	4	5	6	7	8	9	10	11	12	14	
Promethea, St. L..1911	..	1	8	6	4	5	3	1	..	..	..	..	28
Luna, St. L. 1911	..	1	4	5	..	..	1	..	..	..	..	..	11
Luna, Pike Co.....1911	..	4	4	1	..	..	..	..	..	..	..	..	9
Cynthia, N. Y.....1912	..	1	2	..	2	1	..	..	..	..	..	..	6
Polyphemus, St. L. 1911	..	2	..	1	..	..	1	2	1	..	..	..	7
Polyphemus, N. Y. 1912	..	4	1	..	1	..	..	5	..	..	..	..	11
Polyphemus, Ga. ..1913	1	..	1	3	1	..	1	..	..	..	..	2	9
Polyphemus, Mass. 1913	..	..	4	2	6	1	2	..	1	1	..	..	17
Polyphemus, St. L. 1913	..	3	4	8	5	4	7	2	3	2	..	..	38
Total	1	16	28	26	19	11	15	10	5	3	..	2	136

Here we find that most of these 136 insects experienced their most productive day in the prime of their life, or at least before the decadence, for 66% had the most productive day between the second and sixth day of their

life. Hence, as we have said, the insect would lose little if the habit of oviposition were fixed at a later age in order to afford more assurance of a chance of fertilization, since egg-laying is heaviest just after copulation.

THE LAPSE OF TIME BETWEEN THE LAST OVIPOSITION AND DEATH IN RELATION TO THE NUMBER OF EGGS RETAINED AFTER DEATH.

When we consider longevity in its adjustment to egg-laying in order to insure the perpetuation of the species, one is confronted by these problems:

(a) Is life long enough to allow the female an opportunity to complete oviposition? or

(b) Are the females cut off by death before their eggs are all laid?

(c) Is oviposition complete and does the female live for any considerable length of time without eggs to lay, *i. e.*, a useless life?

This table embodies the data from 203 insects. The number of eggs retained by each female when overtaken by death, and the number of days it lived between its last egg-laying and death are presented in Table 23.

The data of table 23 are summarized in Table 24.

Here we readily see that there is no relation between the eggs retained and the time of death. We see in the "A class" 102 insects, half of all used in these observations, which died retaining eggs despite the fact of having 1, 2, 3 or even 6 days of life remaining in which to deposit them; 75 of the insects, or 37% of all observed (class B) were cut short in the midst of egg-laying. The remaining 26 insects, 13% of this population, oviposited completely, 11 of which dutifully died and the remainder lived a useless life of from 1 to 3 days after the completion of egg-laying.

When we see certain females, both fertilized and unfertilized, dying in the midst of oviposition, and others

TABLE 23.

No. of Eggs Retained, and Lapse of Time Between Last Egg-laying and Death.

Promethea U 1911	
Eggs	Days
180	0
177	1
142	0
140	1
130	1
129	1
122	0
99	2
98	1
95	1
54	0
52	0
42	2
41	0
40	0
38	1
27	0
27	2
20	1
20	0
12	1
6	2
6	0
5	0
1	1
1	0
0	0

Promethea M 1911	
Eggs	Days
107	0
85	0
75	0
65	1
61	1
40	1
30	0
25	1
18	0
18	1
13	0
12	1
11	1
8	2
8	0
3	0
2	0
1	0
0	0

Cecropia M 1913	
Eggs	Days
292	2
198	2
140	1
82	1
58	0
43	2
36	0
25	2
11	2
8	2
7	2
7	1
6	2
1	3
0	1

Luna U St. L. 1911	
Eggs	Days
76	1
12	1
10	0
10	0
9	0
3	1
2	1
1	1
0	1
0	3

Pike Co. U, 1911	
185	0
26	2
8	1
0	2
0	0
0	1
0	2
0	0

Pike Co. M, 1911	
2	1
0	2
0	1
0	1

Cynthia M Phil. 1913	
Eggs	Days
344	1
301	2
265	1
260	1
260	1
228	2
224	0
202	0
198	1
175	0
156	2
144	2
113	0
82	2
82	3
50	1
40	1
28	0
8	1
0	0

Cynthia M N. Y. 1913	
Eggs	Days
234	1
198	3
195	1
125	0
120	0
120	1
120	1
120	3
98	1
70	1
65	0
40	0
29	1
25	2
22	1
22	1
20	0
20	1
18	0
16	1
14	0
13	0
12	0
12	2
8	1
0	0

Polyphemus U St. L. 1913	
Eggs	Days
43	0
40	0
36	1
34	0
26	3
26	0
26	3
22	0
21	2
20	0
18	0
17	0
15	1
11	0
11	1
10	0
10	0
10	0
9	2
8	1
5	3
5	0
5	0
4	0
3	1
3	0
3	0
3	0
2	3
2	1
2	0
2	2
0	1
0	0
0	0
0	0
0	0
0	0

Polyphemus U Ga. 1913	
Eggs	Days
131	1
88	2
38	1
24	0
16	1
13	3
13	6
10	3
4	0
0	2
0	1

U, St. L. 1911	
127	1
108	0
23	0
9	0
3	1
0	2
0	1

Polyphemus U F. Riv. 1913	
Eggs	Days
83	0
20	6
13	1
13	1
11	0
9	1
9	2
8	0
8	0
6	3
5	0
4	0
4	1
3	0
2	1
0	3
0	0

TABLE 24.

Lot	Mated or Unmated	Class									Total
		A1	A2	A3	A6	B	C0	C1	C2	C3	
St. L. Promethea 1911	U	10	4	0	0	12	1	0	0	0	27
St. L. Promethea 1911	M	7	1	0	0	10	1	0	0	0	19
St. L. Cecropia 1913	M	3	8	1	0	2	0	1	0	0	15
St. L. Luna 1911	U	2	3	0	0	3	0	2	0	1	11
Pike Co. Luna 1911	U	1	1	0	0	1	2	1	2	0	8
Pike Co. Luna 1911	M	0	0	0	0	1	0	2	1	0	4
Phila. Cynthia 1913	M	8	5	1	0	5	1	0	0	0	20
N. Y. Cynthia 1913	M	12	2	2	0	9	1	0	0	0	26
St. L. Polyphemus 1913	U	6	2	4	0	20	4	1	1	0	38
Ga. Polyphemus 1913	U	3	1	2	1	2	0	1	1	0	11
St. L. Polyphemus 1911	U	3	1	0	0	3	0	0	0	0	7
Mass. Polyphemus 1913	U	4	2	1	1	7	1	1	0	0	17
Total		59	30	11	2	75	11	9	5	1	203

Class A—The number of insects that retained eggs, and had sufficient time to oviposit them in one day (A1), two days (A2), three days (A3), six days (A6).

Class B—The number of insects cut short by death in the midst of egg-laying.

Class C—The number of insects that lived uselessly after completely ovipositing; no days (Co), one day (C1), two days (C2), three days (C3).

completely ovipositing and subsequently continuing a useless life, we can only conclude that egg-laying is not delicately adjusted to the economy of the species, but depends upon the physiological condition of the individual.

Proportion of Sexes.

Darwin, in his discussion of Sexual Selection in his "Descent of Man," places much importance on the proportion of sexes.

The published data on the proportion of sexes, especially of Lepidoptera, are of varying reliability since they often come from the casual collector's notes. As Darwin suggests, these collectors chase after the males because of their prettiness, and in some species the males

are more often on the wing while the heavily ova-laden females remain secluded. In the data here offered, this chance is eliminated since the material was gathered in the cocoon stage, and usually every cocoon seen in the field was taken.

From 1909 to 1911 we recorded the sex of 1214 Saturniid moths (Journ. Exp. Zool., Vol. xii, p. 196), 653 males and 561 females, or a proportion of 116 males to 100 females. In the years 1912 and 1913 we made further records on these moths, and from these data we have constructed the following table:

TABLE 25.

Proportion of Sexes.

Year	Species	Number		Proportion	
		Males	Females	Males	Females
1913	S. cynthia, N. Y.	75	75	100	100
1913	S. cynthia, Phila.	165	138	119	100
1913	C. promethea, Fall River	54	50	108	100
1912	S. californica, Cal.	7	7	100	100
1913	T. polyphemus, St. Louis.....	46	54	85	100
1913	T. polyphemus, Augusta, Ga....	316	285	146	100
1913	T. polyphemus, Fall River.....	101	82	123	100
1912	T. polyphemus, N. Y.....	24	15	160	100
1912	S. cecropia, St. L., R. des P.....	46	33	140	100
1913	S. cecropia, St. L. (fluffy).....	44	35	126	100
1913	S. cecropia, St. Louis.....	174	161	108	100
1913	S. cecropia, South St. Louis....	113	123	92	100
1913	S. cecropia, N. Y.....	76	67	113	100
1913	S. cecropia, Fall River, Mass....	5	4	125	100
	Total	1226	1129	108	100

These records of 2355 insects show the males again slightly in excess, 1226 males to 1129 females. By combining the data for the five years we find the total of 3569 insects comprises 1879 males and 1690 females, or 111 males to 100 females. We shall not presume to say how much significance may be attributed to the fact that

the proportion for all Saturniids observed in the first period, 1909-11, was 116 males to 100 females, while the records for 1912-13 show a proportion of 108 males to 100 females.

The Priority of Male Emergence.

In a study of the duration of life from the standpoint of efficiency for the perpetuation of the species, the fact that in practically all of our Saturniid material the males emerged from 1 to 5 days in advance of the females is a point worthy of thoughtful consideration. Here is the average priority[11] of the males of each population over the females:

TABLE 26.

Callosamia promethea, Fall River	male priority,	3.07 days.
Philosamia cynthia, New York	male priority,	2.64 days.
Philosamia cynthia, Philadelphia	male priority,	1.09 days.
Samia cecropia, New York	male priority,	3.47 days.
Samia cecropia, St. Louis (fluffy)	male priority,	4.98 days.
Samia cecropia, St. Louis, River des Pêres	male priority,	2.56 days.
Samia cecropia, South St. Louis	male priority,	1.84 days.
Telea polyphemus, Augusta, Ga.	male priority,	.23 days.
Telea polyphemus, St. Louis	male priority,	1.48 days.
Telea polyphemus, Fall River	female priority,	3.12 days.

These means give us a concise index to the actual condition occurring for the whole lot. For the details of the rate of emergence throughout the season, and the proportion of the sexes for each day, we present the data in the following curves. (See Pls. I-V.) For making these curves, the two groups of Cynthias, from Philadelphia and New York, were thrown into one lot, since, if plotted singly, the numbers were too small and too scattered upon the field to show the evidence clearly. For the same reason the Cecropias from the fluffy cocoons were combined with the rest of their lot, the River des

[11] The mean date of emergence of males and females was found, and this is the difference between the two.

Pêres Cecropias. The solid lines indicate the number of males emerging on the given day, and the dotted lines the females.

In one or two cases, especially the Polyphemus, the rate of emergence was so uniform or so scattered that this graphic method tells us less than does the simple mean. But in most cases the two lines run generally parallel, with only the space of a day or so between them. In fact, the nicety with which so nearly every increase or decrease in the frequencies of the males is followed by a corresponding change in the females is quite surprising. The female curve follows the male curve like its shadow. For instance in the South St. Louis Cecropias, fig. 6, one could almost estimate from a glance at the curves that the males appear on an average between 1 and 2 days before the females (the calculated mean is really 1.84 days).

Since the males have this precedence in 7 of the 8 lots of material here considered, we feel that it must be more than mere coincidence. The Polyphemus (figs. 2-4) show this difference less than do the other species; in one lot, the Massachusetts Polyphemus (fig. 3) the females show a decided priority, and in the other two lots the priority of the males is not so great as in the other species.

But throughout the series of curves we see unexplained vacillations in the emergence of the whole population, especially in the cases where the lines for both sexes suddenly drop low or to 0 in the midst of the season (as on May 22 in fig. 4, and May 10 in fig. 8), or where the whole population goes up or down together. Here another factor becomes apparent. We add to the list of figures a curve (the broken line, fig. 9) showing the mean temperature for each day, along with the emergence of all insects on that day, all species combined. This explains at a glance a great deal of the fluctuation of the emergence of the entire population, although we cannot see that it exerts a particularly greater influence upon one sex than upon the other. In a large number of cases

a high frequency corresponds to a high temperature on either the same or the preceding day, and a low frequency the corresponding reverse. It is only natural that the parallelism fails after June 10, when at the close of the season only a few stragglers are left to emerge.

Two explanations of this phenomenon of priority of male emergence present themselves. The one suggested by Darwin seems at first thought plausible; that among insects as well as among other groups of the animal kingdom the males emerge or arrive at maturity a little earlier than the females in order that they may have time to travel about and seek out mates, and that the first upon the field will win the mates and leave offspring to perpetuate their habits. In this way it is an adaptation for the good of the species. But on the other hand, in species like these where the duration of the entire life is but a few days, even these 2 or 3 days of priority of the male may suffice to deprive him entirely of a mate. Hence if this condition exist as a natural law it is at least subject to many drawbacks and defeats by other conflicting factors. The other explanation is that the duration of the pupal life of the male is shorter than that of the female, owing to the fact that the female has the large mass of ova to produce, and that this difference in time required for development becomes apparent at this particular point in the life of the individual.

Fertility of Saturniid Eggs in Relation to the Mating Period.

INTRODUCTORY REMARKS.

The Saturniid moths, at least the ones with which we have worked, spend much time in mating. The Cecropia moth spends from 10 to 48 hours in copulo, or 21 hours on an average.[12] We have found that a normal mating for all of these species Cynthia, Polyphemus, Cecropia or Californica, consists of a continuous period in copulo

[12] Trans. Acad. Sci., St. Louis, 20: 309, 1911.

from early morning, 4 to 6 o'clock, to the evening of the same day, the couples usually severing some time between 5 and 9 o'clock. This length of time seems enormous when we consider the brief period they have wherein to live and reproduce. We wondered whether this prolonged period was of any increased value to the species; whether a longer period of copulation tended to insure the fertility of all of the eggs, or whether a large number of ova required a longer period of mating to insure the fertility of all.

We also wanted to know just what per cent of the eggs were fertile, and if there was a higher percentage of fertility among the first eggs deposited than among the last.

This led to the experiments with Cecropia eggs from insects which mated from 3 to 48 hours.[13] In this study we found that there is absolutely no relation between the time spent in copulation and the fertility of the eggs; that those insects which remained in copulo for 3 to 15 hours deposited eggs showing just as high a per cent of fertility as those which continued for 18 to 48 hours. We also found that those insects which carried an abnormally large number of eggs had just as large a per cent of fertility as did those with smaller numbers. In the former work we found 77% of all the eggs were fertile and 23% infertile.

In 1913 similar work was carried on with 132 females of the following 8 lots of Saturniids:

22 ♀'s Samia cecropia, River des Pêres, St. Louis, normal.....1913
14 ♀'s Samia cecropia, River des Pêres, St. L., fluffy cocoons.....1913
11 ♀'s Samia cecropia, South St. Louis.....1913
16 ♀'s Samia cecropia, New York 1913
27 ♀'s Philosamia cynthia, Philadalphia 1913
30 ♀'s Philosamia cynthia, New York 1913
10 ♀'s Telea polyphemus, Fall River (2♀'s) 1913
Telea polyphemus, St. Louis (1♀) 1912
Telea polyphemus, New York (1♀) 1912
Telea polyphemus, Augusta, Ga. (6♀'s) 1913
2 ♀'s Samia californica, California 1912

[13] The details of this work were published in Biol. Bull., 24: 245-250, 1913.

The individuals were isolated immediately upon leaving the cocoon, and placed one pair in a cage. Frequently some eggs were dropped ere mating began, but these were in all cases vigilantly removed and not taken into account. Early each morning the eggs from each cage were counted and placed in a vial with a cotton stopper and labeled; this comprised the oviposition of the preceding 24 hours. The emerging caterpillars all died in their vials. Later, these as well as the empty egg-shells were counted, and all of the eggs from which nothing had hatched were dissected, to find whether they contained an embryo or were infertile. In all of this material, as in the former lot, all of the eggs that were shriveled proved infertile and contained only a dried mass of yellowish substance.[14] It also sometimes happened that the smooth, round eggs of the Cecropia contained a fully-formed insect which had been unable to bite its way out. There were, however, a few exceptions in each class, and the external appearance was not relied upon, but each egg was cut open and the contents examined. The small number of fertile eggs which had the opening partly cut by the caterpillar in attempting to emerge were in every case counted with those which normally emerged.

The tables give the number of hours spent by each female in copulo. The letter "N" signifies a normal, free mating, which means that mating began in the early morning hours and continued throughout the day until evening. Each day's deposit is recorded separately, and separated into the following four classes:

T—Total number of eggs deposited that day.

F H—The number in this day's deposit that were fertile and hatched.

F U—The number fertile but unhatched.

Inf—Infertile.

*—Eggs were deposited on this day, but were included in the next day's count.

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[14] In the Cynthia eggs this mass was dark brown.

SAMIA CECROPIA.

Table 27 presents the data of the fertility of the River des Pêres Cecropias coming from the normal cocoons.

We have 9 insects recorded above which mated from 4 to 6 hours. A glance at the total column promptly tells us that the per cent of infertility is so low that the egg masses may be called practically all fertile. These pairs were artificially separated after having been together for 5 or 6 hours, or in one case 4 hours.

In connection with the normal period of copulation, 15 to 18 hours, we have 11 insects which show the per cent of infertility to be correspondingly low. On the whole, this entire lot of eggs were very fertile; the 4704 eggs included only 106 infertile ones, or 2.2%, while 97.8% of the aggregate were fertile.

We cannot see any perceptible difference in the fertility of the early or late deposition, but the smallness of the per cent of the infertile eggs in the total deposit would make it an increasingly delicate task to detect such a difference. This year's material shows a much higher degree of fertility than that for the year 1911.

In the total F. U. column of the table is given the number of eggs in which the embryo partially developed but for some unknown cause died in the shell. These constitute 3.8% of the whole number of eggs deposited, and 4% of the fertile eggs, a far smaller proportion than the 1911 eggs, which showed 11% and 14.5% respectively unhatched though fertile.

Here we see clearly that a shortened period of mating does not reduce the fertility of the eggs; that the insect could economize on time spent in copulation and still cause no reduction in the progeny, or that in some cases she might even increase the number of her offspring by utilizing this extra time for oviposition, in which she might otherwise be cut short.

TABLE 27.

Fertility of Eggs of S. cecropia. *St. Louis, River des Peres, 1913.*

(*Normal Cocoons.*)

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				7th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
1	4	51	49	2	0	*	...	...	...	122	119	0	3	126	110	16	0	10	10	0	0	...	...	...	...	...	...	...	...	309	288	18	3
2	5–6	107	88	15	4	139	130	7	2	12	10	2	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	258	228	24	6
3	5–6	110	110	0	0	*	...	...	...	123	116	5	2	64	61	3	0	...	...	...	...	...	...	...	...	...	...	...	...	297	287	8	2
4	5–6	151	143	7	1	*	...	...	...	64	64	0	0	107	100	4	3	1	1	0	0	...	...	...	...	...	...	...	...	323	308	11	4
5	5–6	65	61	2	2	*	...	...	...	209	200	7	2	*	...	...	...	63	58	4	1	...	...	...	...	...	...	...	...	337	319	13	5
6	5–6	171	164	0	7	*	...	...	...	42	34	8	0	*	...	...	...	14	13	1	0	...	...	...	...	...	...	...	...	227	211	9	7
7	5–6	167	167	0	0	*	...	...	...	72	67	0	5	23	9	2	12	...	...	...	...	...	...	...	...	...	...	...	...	262	243	2	17
8	5–6	152	147	4	1	*	...	...	...	53	52	1	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	205	199	4	2
9	5–6	24	18	6	0	36	31	5	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	60	49	11	0
10	N	200	193	1	6	59	59	0	0	27	22	5	0	51	49	2	0	10	6	3	1	1	1	0	0	...	...	...	...	348	330	11	7
11	N	45	40	0	5	2	2	0	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	47	42	0	5
12	N	7	5	0	2	54	53	0	1	*	...	...	...	95	95	0	0	42	31	3	8	...	...	...	...	...	...	...	...	198	184	3	11
13	N	31	26	2	3	47	46	1	0	97	89	4	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	175	161	7	7
14	N	62	62	0	0	147	145	2	0	79	63	14	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	288	270	16	2
15	N	81	77	2	2	*	...	...	...	32	32	0	0	*	...	...	...	*	...	...	...	...	...	...	...	...	...	...	...	310	291	15	4
16	N	72	72	0	0	*	...	...	...	192	186	5	1	47	44	1	2	...	...	...	...	197	182	13	2	...	...	...	...	311	302	6	3
17	N	10	9	1	0	*	...	...	...	33	33	0	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	43	42	1	0
18	N	*	...	...	...	198	198	0	0	182	179	2	1	8	7	1	0	...	...	...	...	...	...	...	...	...	...	...	...	388	384	3	1
19	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	...	...	...	...	210	175	16	19
20	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	108	106	1	1	108	106	1	1
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4704	4419	179	106

The same kind of notes were made on 13 of the insects from the large, fluffy cocoons in an attempt to detect any points which might seem characteristic of this group. (See Table 28.)

Here we have 9 insects which mated normally, and all but one yield a very small number of infertile eggs. We have also 2 females with the mating period prolonged to 36 and 38 hours; here also is a very low per cent of infertility. Then we have the opposite extreme, 2 which were separated after only 6 and 2 hours in mating, and even here the fertility is almost perfect. In the earlier series of experiments we were afraid to cut the mating shorter than 3 hours, but here a 2-hour period in copulo seemed quite as sufficient for perfect results as a much longer one.[15] On the whole, the insects from the fluffy cocoons show a very slightly higher per cent of infertility than the normal Cecropias of this lot, but the influence of two extreme individuals is responsible for this. This infertility, however, even if it were more than mere chance of this material, could not be of any effect toward the elimination of this variety (if these do constitute a variety, with their own peculiar characteristics maintained by heredity), because, as we have seen in a previous chapter, they produce a larger number of ova than do the normal Cecropias. Hence fluffiness is not correlated with fertility, though it might be with fecundity. In this lot we find a low proportion, 5%, of the fertile ova which failed to produce larvae. This indicates that this group of parents are a vigorous stock. We also see in this lot no correlation between early and late oviposition and infertility.

For some undiscovered reason, the material of this year shows a much lower per cent of infertility than did the 1911 collections. Also in this lot we found no individuals which, after either a normal, prolonged or shortened mating, still had all of the eggs infertile as we did

[15] See p. 61 for discussion of 1-hour matings.

TABLE 28.

Fertility of Eggs of S. cecropia. *St. Louis, River des Peres, 1913.*

(*Fluffy Cocoons.*)

♀ No.	Hours in Copula	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				7th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
21	N	93	89	1	3	121	119	0	2	*	...	...	...	5	5	0	0	*	...	...	...	27	24	2	1	...	...	...	...	246	237	3	6
22	N	5	5	0	0	79	79	0	0	72	72	0	0	82	78	4	0	51	51	0	0	12	12	0	0	...	...	...	...	301	297	4	0
23	N	24	22	2	0	96	86	10	0	101	66	6	29	50	48	1	1	10	10	0	0	23	21	1	1	1	1	0	0	305	254	20	31
24	38	67	65	1	1	58	52	5	1	99	96	2	1	111	106	3	2	77	76	0	1	30	27	1	2	...	...	...	...	442	422	12	8
25	36	44	44	0	0	49	48	0	1	90	79	10	1	69	63	6	0	25	24	1	0	...	...	...	...	...	...	...	...	277	258	17	2
26	N	6	5	1	0	23	21	2	0	131	131	0	0	0	0	0	0	149	148	0	1	2	2	0	0	...	...	...	...	311	307	3	1
27	N	122	88	0	34	176	160	3	13	0	0	0	0	43	36	6	1	19	8	10	1	...	...	...	...	...	...	...	...	360	292	19	49
28	N	171	128	39	4	6	5	1	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	177	133	40	4
29	N	166	159	3	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	166	159	3	4
30	N	240	228	6	6	*	...	...	...	100	97	0	3	58	42	14	2	...	...	...	...	...	...	...	...	...	...	...	...	398	367	20	11
31	N	102	98	0	4	68	54	12	2	*	...	...	...	53	43	9	1	...	...	...	...	...	...	...	...	...	...	...	...	223	195	21	7
32	6	164	148	9	7	*	...	...	...	103	102	0	1	11	8	3	0	...	...	...	...	...	...	...	...	...	...	...	...	278	258	12	8
33	2	78	65	2	11	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	78	65	2	11
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3562	3244	176	142

in the first lot. Then again we find that the duration of copulation does not influence the fertility of the eggs, whether they be few or many. (See Table 29.)

We shall not go into the analysis of these data of the South St. Louis Cecropias, since the per cents correspond so closely to those already discussed. (See Table 30.)

The New York Cecropias furnish very interesting comparative data. The per cents of fertility and viability are practically identical with those from a distant locality of different climate. (See Table 30.)

This lot is rich in 2-hour matings, which give the same good results of high fertility—much higher in fact than some of the normal matings. This again conclusively demonstrates that 2 hours of copulation is quite sufficient for the propagation of the race.

PHILOSAMIA CYNTHIA.

Our observations on the fertility in *P. cynthia* are based upon two lots of material, one from New York City and one from Philadelphia, Pa.

This species seems not to be monogamous, like our Cecropias, but some of the New York insects mated twice, and some members of the Philadelphia lot mated two and three times. Normal mating in this species is the same as in the Cecropias, *i. e.,* continuous mating from early morning until about dark, or sometimes a little later. It will be noted that in both tables a few individuals have no record of length of time in mating. In these cases they were found already in copulo when the examination was made in the morning, and they had already separated before the usual time of inspection in the afternoon, so we do not know with certainty the exact duration of the mating. In the cases where they were artificially separated, the duration is indicated by the number placed after the date of mating.

The counting of the empty egg-shells and the dead larvae in each vial was a comparatively easy task, but

TABLE 29.

Fertility of Eggs of S. cecropia. *South St. Louis, 1913.*

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				7th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
34	N	8	7	0	1	22	22	0	0	42	40	2	0	96	96	0	0	67	65	2	0	29	25	4	0	3	3	0	0	267	258	8	1
35	28	65	44	21	0	113	82	26	5	39	27	11	1	2	1	1	0	...	...	...	...	...	...	...	...	...	...	...	...	219	154	59	6
36	N	50	48	2	0	131	120	4	7	*	...	...	...	119	116	1	2	5	3	1	1	...	...	...	...	...	...	...	...	305	287	8	10
37	N	223	221	0	2	28	28	0	0	*	...	...	...	31	27	4	0	*	...	...	...	*	...	...	...	30	25	3	2	312	301	7	4
38	N	24	21	2	1	187	180	5	2	*	...	...	...	*	...	...	...	*	...	...	...	67	57	10	0	...	...	...	...	278	258	17	3
39	N	73	60	3	10	96	94	2	0	*	...	...	...	60	59	1	0	*	...	...	...	*	...	...	...	14	14	0	0	243	227	6	10
40	N	12	10	2	0	*	...	...	...	75	75	0	0	*	...	...	...	110	104	5	1	*	...	...	...	74	63	5	6	271	252	12	7
41	5½	7	7	0	0	*	...	...	...	152	149	3	0	*	...	...	...	77	74	3	0	*	...	...	...	6	6	0	0	242	236	6	0
42	6	70	65	5	0	*	...	...	...	92	80	9	3	*	...	...	...	45	43	2	0	...	...	...	...	...	...	...	...	207	188	16	3
43	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	123	111	4	8	123	111	4	8
44	2	146	116	14	16	50	47	3	0	*	...	...	...	15	13	0	2	...	...	...	...	...	...	...	...	...	...	...	...	211	176	17	18
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2678	2448	160	70

TABLE 30.

Fertility of Eggs of S. cecropia. *New York, 1913.*

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
45	2	178	118	60	0	*	...	...	...	70	32	38	0	...	...	...	...	...	...	...	...	...	...	...	...	248	150	98	0
46	N	98	94	1	3	53	51	1	1	*	...	...	...	3	3	0	0	1	1	0	0	...	...	...	...	155	149	2	4
47	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	170	166	4	0	170	166	4	0
48	2	62	61	1	0	*	...	...	...	21	17	3	1	...	...	...	...	...	...	...	...	...	...	...	...	83	78	4	1
49	2	*	...	...	...	177	175	1	1	102	98	4	0	*	...	...	...	*	...	...	...	44	36	6	2	323	309	11	3
50	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	264	254	10	0	264	254	10	0
51	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	326	266	52	8	326	266	52	8
52	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	295	235	20	40	295	235	20	40
53	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	248	220	7	21	248	220	7	21
54	5½	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	279	264	5	10	279	264	5	10
55	5	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	280	233	21	26	280	233	21	26
56	5	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	336	311	8	17	336	311	8	17
57	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	259	244	14	1	259	244	14	1
58	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	190	175	6	9	190	175	6	9
59	N	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	*	...	...	...	226	207	5	14	226	207	5	14
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3682	3261	267	154

dissecting the eggs which did not hatch was a far more difficult task than in the Cecropia studies. In the latter species, the eggs which gave forth nothing showed upon dissection one of two alternatives; the egg contained either a well-formed embryo, easily distinguished, or a yellow mass of dried egg substance. In the Cynthias the eggs were very much smaller, and the contents, whether the egg mass or the dead embryo, were in most cases dark brown, and it required examination under magnification to determine whether the masses were infertile or had partly developed. This scrutiny revealed the fact that mortality had occurred at all stages of the embryonic development. (See Table 31.)

Here are 30 females which deposited a total of 6931 eggs. Of this number 2815 (or 41%) normally hatched, and 1584 (23%) were infertile, while the remaining 36% of the total number deposited failed to develop to maturity, or died in embryo. This is the most extreme case of waste that we have yet found. Attempts were made to sift the data and cull some indication of the causes of this, but nothing positive was found.

The females in this table, 15 in number, which experienced one mating of unknown duration (probably slightly abbreviated), were brought together in a separate table, but these showed all degrees of fertility and infertility. The 5 moths which mated twice deposited a large number of infertile ova, in spite of the additional opportunity for their fertilization. The 7 females which went through a normal period of mating were likewise assembled. The fertility in these is fairly good although the per cent. does not run nearly so high as in the other species earlier considered. There are only 3 individuals in this table in which the artificial interruption of mating was practiced. One was in copulo 6 hours, but the next day mated again; in this case almost all of the eggs were fertile. In the next, after a 3-hour period of mating 68 eggs, or about 20% of the whole number, were infertile, and the

TABLE 31.

Fertility of Eggs of P. cynthia. *New York, 1913.*

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
60	N	136	130	5	1	25	13	2	10	13	5	5	3	15	2	3	10	...	...	...	...	...	...	...	...	189	150	15	24
61	?	82	45	31	6	29	11	14	4	6	2	4	0	...	...	...	...	...	...	...	...	...	...	...	...	117	58	49	10
62	?	77	21	47	9	66	7	52	7	53	0	23	30	4	0	4	0	...	...	...	...	...	...	...	...	200	28	126	46
63	N	180	130	50	0	43	0	40	3	34	0	32	2	2	0	1	1	...	...	...	...	...	...	...	...	259	130	123	6
64	N	48	14	32	2	12	0	12	0	3	0	1	2	...	...	...	...	...	...	...	...	...	...	...	...	63	14	45	4
65	?	22	2	12	8	75	15	33	27	36	1	23	12	116	20	96	0	...	...	...	...	...	...	...	...	249	38	164	47
66	?	59	8	38	13	22	6	16	0	...	...	...	...	1	0	1	0	...	...	...	...	...	...	...	...	82	14	55	13
67	N	7	0	6	1	172	69	92	11	29	3	14	12	16	0	0	16	7	0	0	7	...	...	...	...	231	72	112	47
68	?	208	190	13	5	15	0	15	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	223	190	28	5
69	N+N	121	83	28	10	138	0	135	3	53	0	40	13	57	0	47	10	27	0	5	22	27	0	0	27	423	83	255	85
70	?	71	0	64	7	54	0	54	0	53	0	33	20	35	7	16	12	56	10	28	18	...	...	...	...	269	17	195	57
71	N	44	6	26	12	53	22	29	2	11	1	9	1	11	2	9	0	...	...	...	...	...	...	...	...	119	31	73	15
72	N	143	30	103	10	47	2	28	17	105	50	40	15	84	16	16	52	...	...	...	...	...	...	...	...	379	98	187	94
73	?	168	84	79	5	85	29	50	6	6	0	0	6	...	...	...	...	...	...	...	...	...	...	...	...	259	113	129	17
74	N+N	172	120	29	23	26	0	16	10	44	5	38	1	...	...	...	...	...	...	...	...	...	...	...	...	242	125	83	34
75	?+?	126	32	79	15	124	20	102	2	77	15	30	32	40	0	21	19	27	0	9	18	...	...	...	...	394	67	241	86
76	?	200	130	60	10	64	20	25	19	24	0	7	17	...	...	...	...	...	...	...	...	...	...	...	...	288	150	92	46
77	?	149	43	43	63	106	50	34	22	73	59	8	6	2	0	1	1	...	...	...	...	...	...	...	...	330	152	86	92
78	?	66	28	31	7	179	157	12	10	49	20	25	4	2	0	2	0	...	...	...	...	...	...	...	...	296	205	70	21
79	?	117	0	0	117	24	0	0	24	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	141	0	0	141
80	?	273	248	10	15	37	9	23	5	27	5	14	8	...	...	...	...	...	...	...	...	...	...	...	...	337	262	47	28
81	?	165	105	55	5	76	43	28	5	23	13	10	0	...	...	...	...	...	...	...	...	...	...	...	...	264	161	93	10
82	?	76	28	13	35	120	50	25	45	126	0	8	118	2	0	0	2	...	...	...	...	...	...	...	...	324	78	46	200
83	6+?	172	145	12	15	26	11	12	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	198	156	24	18
84	3	195	150	30	15	50	22	13	15	68	0	30	38	3	0	3	0	...	...	...	...	...	...	...	...	316	172	76	68
85	3	83	48	30	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	83	48	30	5
86	N	116	66	20	30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	116	66	20	30
87	N+N	28	0	0	28	67	0	0	67	14	0	0	14	...	...	...	...	...	...	...	...	...	...	...	...	109	0	0	109
88	?	140	123	2	15	39	3	10	26	3	1	1	1	...	...	...	...	...	...	...	...	...	...	...	...	182	127	13	42
89	?+?	63	0	10	53	66	0	40	26	66	0	5	61	54	0	0	54	...	...	...	...	...	...	...	...	249	0	55	194
Total.....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6931	2815	2532	1584

third case, after a like period of 3 hours, showed a very low per cent. of infertility.

With so much individuality apparent we cannot yet point out any causal factors of this variability in the fertility of this species. We present the data of the "Fertile Unhatched" column without any more comment than to say that here too we find the same variability as elsewhere; in the ova of some individuals the embryonic mortality is high, and in others comparatively low. Whether or not this lack of viability of the fertile ova is due to some factor in the St. Louis conditions, temperature or humidity, we cannot tell. To be sure this species is typical of the Atlantic states and does not occur at St. Louis, and the environmental conditions here may have affected this material. But the fact that a considerable per cent. of the fertile eggs hatched normally shows that the climate is not intolerable to some of them at least, so the problem remains: What are the special characteristics or weaknesses of certain other individuals which predetermine that they shall not be able successfully to reproduce, or having been produced, to survive?

Parallel work was done with 27 fertilized females from Philadelphia, with the results shown in the table below. (See Table 32.)

In this lot we see an appallingly great degree of infertility, and also a much higher per cent. of the fertile eggs which failed to hatch. Of the 4416 eggs deposited by this lot only 1215, or 27.5%, gave forth caterpillars. Even the New York lot, which we considered very weak, gave 41% fertility. Almost one-half of these eggs laid were infertile, and about half of the fertile eggs failed to bring their development to completion. Thus we see this Philadelphia population in a sad plight in regard to their perpetuation. Elimination in the early stages of life is common in all branches of the animal kingdom, but this, an elimination of nearly three-fourths of the

TABLE 32.

Fertility of Eggs of S. cynthia. *Philadelphia, 1913.*

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
90	N	255	232	15	8	20	0	15	5	23	0	11	12	12	0	0	12	11	0	0	11	...	...	...	...	321	232	41	48
91	5	124	84	18	22	21	1	5	15	9	0	1	8	...	...	...	...	...	...	...	...	...	...	...	...	154	85	24	45
92	?	258	198	45	15	13	0	7	6	3	0	0	3	...	...	...	...	...	...	...	...	...	...	...	...	274	198	52	24
93	N	73	8	42	23	21	3	15	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	94	11	57	26
94	?+N	68	39	15	14	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	68	39	15	14
95	N	175	110	65	0	22	1	5	16	4	0	1	3	...	...	...	...	...	...	...	...	...	...	...	...	201	111	71	19
96	?	235	201	15	19	27	0	11	16	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	262	201	26	35
97	N	117	69	30	18	44	0	34	10	11	0	9	2	3	0	0	3	1	0	0	1	1	0	0	1	177	69	73	35
98	?+?+?	208	154	15	39	...	...	...	...	4	0	3	1	12	0	4	8	...	...	...	...	...	...	...	...	224	154	22	48
99	?	65	2	33	30	16	0	14	2	71	0	49	22	1	0	0	1	...	...	...	...	...	...	...	...	153	2	96	55
100	?+?	115	60	40	15	7	0	3	4	4	0	3	1	...	...	...	...	...	...	...	...	...	...	...	...	126	60	46	20
101	?	49	0	45	4	13	0	2	11	3	0	0	3	5	0	0	5	6	0	0	6	2	0	0	2	78	0	47	31
102	7+2+?	159	45	109	5	88	5	60	23	29	0	23	6	26	0	1	25	3	0	0	3	...	...	...	...	305	50	193	62
103	?	135	0	0	135	6	0	0	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	141	0	0	141
104	?	21	0	0	21	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	21	0	0	21
105	?	33	0	0	33	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	33	0	0	33
106	1	51	0	25	26	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	51	0	25	26
107	?+?+?	28	0	10	18	43	0	18	25	59	0	19	40	37	0	0	37	3	0	0	3	...	...	...	...	170	0	47	123
108	?+?	117	0	40	77	48	1	20	27	28	0	0	28	40	0	10	30	6	0	0	6	...	...	...	...	239	1	70	168
109	?	60	0	15	45	52	0	25	27	61	0	60	1	11	0	3	8	...	...	...	...	...	...	...	...	184	0	103	81
110	?	...	...	...	...	147	0	102	45	55	0	0	55	14	0	0	14	...	...	...	...	...	...	...	...	216	0	102	114
111	?	61	0	26	35	50	2	10	38	7	0	0	7	...	...	...	...	...	...	...	...	...	...	...	...	118	2	36	80
112	?+?	8	0	0	8	22	0	0	22	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	30	0	0	30
113	?	135	0	0	135	49	0	0	49	34	0	0	34	47	0	0	47	...	...	...	...	...	...	...	...	265	0	0	265
114	?+?	27	0	0	27	112	0	0	112	39	0	0	39	...	...	...	...	...	...	...	...	...	...	...	...	178	0	0	178
115	N+?	12	0	0	12	32	0	0	32	77	0	0	77	...	...	...	...	...	...	...	...	...	...	...	...	121	0	0	121
116	?	203	0	0	203	9	0	0	9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	212	0	0	212
Total.....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4416	1215	1146	2055

ova produced before they had even hatched from the egg, is unusual. Not only the means for the entire lot show a low per cent. of fertility, but the records of the individuals also show that only 8 out of the 27 females were successful in contributing even a fair number of living young to the next generation. Nor can we glean from these data any evidence that repeated or prolonged matings increase the fertility of the egg masses, or that somewhat abbreviated mating reduces it. The careful search for such evidence revealed the fact that those individuals which mated the full time or even twice or thrice showed as high a proportion of infertile or non-viable ova as the others, while good and bad cases of fertility appear also in those females which mated only a few hours. This evidence strengthens our belief that in this species, as in Cecropia, an amount of sperm sufficient for the fertilization of the ordinary mass of ova enters the seminal receptacle very early in the mating period; the ova pass through this male element, and if they are capable of fertilization they become fertilized by this contact, and those unfit pass out without the wherewithal for development, and copulation for a greater length of time will have no effect upon these ova which are not perfect to receive the spermatozoa.

TELEA POLYPHEMUS.

The difficulty of inducing the Polyphemus to mate has been explained elsewhere. The data on 10 fertilized females from several localities are given below. (See Table 33.)

The 2 insects from Fall River deposited ova of a high per cent. of fertility, but the one which mated only 9 hours was superior in fertility to her sister who spent 13 hours in copulo. The one female which was taken at the light one evening in St. Louis, with history unknown, deposited 66 eggs, every one of which was fertile. The 6 females from Augusta, Ga., which mated from 12

TABLE 33.

Fertility of Eggs of T. polyphemus.

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				7th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
†117	9	116	112	4	0	146	144	0	2	25	25	0	0	22	21	1	0	24	23	0	1	16	9	6	1	5	5	0	0	354	339	11	4
†118	13	74	57	5	12	126	125	0	1	42	39	2	1	10	9	0	1	4	4	0	0	4	4	0	0	...	...	...	...	260	238	7	15
‡119	?	46	46	0	0	11	11	0	0	4	4	0	0	5	5	0	0	...	...	...	...	...	...	...	...	...	...	...	...	66	66	0	0
§120	?	70	50	15	5	31	24	7	0	14	14	0	0	5	5	0	0	...	...	...	...	...	...	...	...	...	...	...	...	120	93	22	5
*121	12	172	157	5	10	29	11	16	2	1	1	0	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	202	169	21	12
*122	?	112	78	21	13	3	3	0	0	5	3	0	2	4	0	0	4	...	...	...	...	...	...	...	...	...	...	...	...	124	84	21	19
*123	15	45	25	17	3	12	8	2	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	57	33	19	5
*124	15	10	7	2	1	11	8	0	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	21	15	2	4
*125	14	209	116	52	41	13	2	2	9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	222	118	54	50
*126	?	140	125	11	4	28	23	4	1	15	9	6	0	8	4	0	4	...	...	...	...	...	...	...	...	...	...	...	...	191	161	21	9
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1617	1316	178	123

†Fall River, Mass. ‡St. Louis, 1912. §New York, 1912. *Augusta, Ga.

TABLE 34.

Fertility of S. Californica. California, 1912.

♀ No.	Hours in Copulo	1st Day's Deposit				2nd Day's Deposit				3rd Day's Deposit				4th Day's Deposit				5th Day's Deposit				6th Day's Deposit				7th Day's Deposit				Total			
		T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	T	F H	F U	Inf.	Dep.	F H	F U	Inf.
127	28	232	96	88	48	18	18	0	0	36	18	13	5	4	4	0	0	4	1	0	3	2	0	0	2	...	...	...	...	296	137	101	58
128	13	195	166	28	1	71	70	0	1	31	14	17	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	197	150	45	2
Total....		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	493	287	146	60

to 15 hours, gave a total of 817 eggs, 12% of which were infertile.

SAMIA CALIFORNICA.

For the *Samia californica* we have notes on only 2 insects. (See Table 34.)

The first mated 28 hours and yielded 20% of infertile eggs, while the second, after only a 13-hour mating had barely 1% of infertile eggs.

THE MINIMUM DURATION OF MATING IN RELATION TO FERTILITY.

In our four Cecropia tables already presented are 6 females which mated only 2 hours, yet had a perfectly normal proportion of fertile eggs, while the seventh was entirely infertile. We were eager to find just what the minimum duration of copulation could be to insure the fertility of a normal amount of eggs.

The period of mating of 3 females was limited to 1 hour, and of 1 female, to 2 hours; from all these, not one egg was fertile.

Hence the minimum duration of mating required for complete fertilization of the egg mass must be between 1 and 2 hours. Of course the one insect which mated for 2 hours and yet gave no evidence of fertilization may have been sterile, since we have data on a number of 2-hour matings, recorded elsewhere, a large proportion of which proved quite fertile.

Period of Incubation.

SAMIA CECROPIA.

In a previous series of observations on the period of incubation of Crecopia eggs,[16] we found the period of incubation for the eggs deposited each day by each female to vary from 6 to 11 days. The length of time for the great majority was 8 or 9 days. All but two of the 36

[16] Psyche. 19: 69, 1912.

females deposited their first eggs between June 9 and 26. Our principal object in this work was to see whether or not the eggs which were laid on different days required the same length of time for their development, whether the first eggs deposited have the same period of incubation as do the last eggs. In the notes already referred to we found this time to be the same for all the ova of each female, whether they were laid on the first or on the last day of her oviposition, and in the few cases where fluctuation occurred in the eggs of an individual, the variation was within one day. We therein suggested that when such variation occurred it may have been due to climatic variations.

The same problem was pursued in 1912-13 on the four species of Saturniids herein dealt with. The results of the work are summarized in the tables below, which show the number of days required for the hatching of each female's eggs deposited on the 1st, 2nd . . . 8th day of oviposition. (See Tables 35, 36, 37, 38.)

For all of the four lots of Cecropias we find the duration of incubation to be from 12 to 16 days. As a rule one finds no variation due to their early or late deposition.

What a striking difference there is between the period of incubation of these four lots, with a mode of 14 days, and the lot of 1911, in which the period was only 6 to 11 days, with the mode at 8 or 9 days. We can account for the radical difference only by the fact that the eggs of the 1911 lot were laid a whole month later in the year than those of the present study. Inspection of the United States Meteorological Reports for these two periods when the eggs were incubating reveals that the mean temperature for June, 1911, was 79° F., while that of May, 1913, was 67.5°. So the cause of this difference may be only a matter of climatic conditions; the eggs laid at a warm time late in the season hatched much sooner than those exposed to the colder air earlier in the spring.

TABLE 35.

Period of Incubation. Eggs of S. cecropia. St. Louis, River des Peres, 1913, (Normal).

♀ No.	Day's Deposit							Date of 1st Day's Deposit
	1	2	3	4	5	6	7	
A	14	15	15	14	14	13	13	5-14
B	15	14	14	?	13	..	..	5-15
C	14	13	13	..	..	..	..	5-16
D	14	14	..	..	..	..	..	5-16
E	14	14	14	13	..	..	..	5-16
F	14	14	14	13	..	..	..	5-16
G	14	13	13	12	12	..	..	5-17
H	13	13	13	..	..	..	..	5-16
I	14	14	..	12	..	..	..	5-16
J	13	13	13	12	..	..	..	5-16
K	13	13	13	13	..	..	..	5-17
L	13	13	13	13	..	..	..	5-17
M	14	14	..	..	..	..	..	5-17
N	13	13	13	..	..	..	..	5-17
O	14	13	13	13	..	..	..	5-17
P	14	13	13	13	..	..	..	5-17
Q	14	13	13	12	..	..	13	5-17
R	14	13	..	..	..	..	..	5-17
S	14	?	12	..	..	..	..	5-17

TABLE 36.

Period of Incubation. Eggs of S. cecropia. St. Louis, River des Peres, 1913. (Fluffy).

♀ No.	Day's Deposit								Date of 1st Day's Deposit
	1	2	3	4	5	6	7	8	
A	15	14	15	14	14	15	..	..	5-11
B	14	15	14	14	14	14	14	..	5-12
C	14	15	14	14	14	14	14	14	5-12
D	14	15	14	14	14	..	..	..	5-12
E	15	14	14	14	14	14	14	14	5-13
F	14	15	14	14	14	14	..	..	5-14
G	14	..	..	..	..	..	..	..	5-15
H	15	14	..	..	..	..	..	..	5-15
I	14	..	..	..	..	..	..	..	5-15
J	15	14	14	14	12	..	..	..	5-15
K	14	?	14	..	..	..	..	..	5-16
L	14	14	14	14	..	..	..	..	5-16
M	?	?	?	?	12	..	..	..	5-17

TABLE 37.

Period of Incubation. Eggs of S. cecropia. South St. Louis, 1913.

♀ No.	Day's Deposit								Date of 1st Day's Deposit
	1	2	3	4	5	6	7	8	
A	16	15	14	13	14	14	14	14	5-10
B	15	14	14	14	..	..	..	..	5-12
C	14	14	14	14	..	..	..	..	5-13
D	15	14	14	13	13	13	..	..	5-15
E	15	14	14	14	13	..	..	..	5-15
F	14	14	14	14	..	..	..	..	5-15
G	14	13	13	13	..	..	..	..	5-16
H	15	14	13	13	..	..	..	..	5-16
I	14	13	13	..	..	..	..	..	5-17
J	14	?	?	12	12	..	..	..	5-17

TABLE 38.

Period of Incubation. Eggs of S. cecropia. New York, 1913.

♀ No.	Day's Deposit				Date of 1st Day's Deposit
	1	2	3	4	
A	15	14	15	14	5-15
B	13	12	..	..	5-18

TELEA POLYPHEMUS.

Owing to the difficulty in getting Polyphemus to mate in confinement, we have records on only 10 individuals of this species from the different localities. (See Tables 39, 40, 41.)

In this species too we see that the period of incubation is influenced by the date of oviposition. For instance, in Table 39 we have the eggs of 5 females laid in June; these have a period of 6 to 8 days. In this same table we have another lot of eggs deposited on May 20 which required 11 days. In Table 40 are the eggs from two insects, one's oviposition commencing on May 11 and the other on June 10; the earlier lot required 11 to 13

TABLE 39.

Period of Incubation. T. polyphemus. Augusta, Ga., 1913.

♀ No.	Day's Deposit				Date of 1st Day's Deposit
	1	2	3	4	
A	11	..	..	..	5-20
B	8	..	8	..	6-13
C	7	7	..	..	6-15
D	6	6	6	..	6-17
E	7	7	..	..	6-15
F	7	7	7	..	6-24

TABLE 40.

Period of Incubation. Eggs of T. polyphemus. Fall River, Mass., 1913.

♀ No.	Day's Deposit						Date of 1st Day's Deposit
	1	2	3	4	5	6	
A	11	11	13	12	13	13	5-11
B	10	9	8	8	9	..	6-10

TABLE 41.

Period of Incubation. Eggs of T. Polyphemus. St. Louis, 1912.

♀ No.	Day's Deposit				Date of 1st Day's Deposit
	1	2	3	4	
A	8	8	8	8	7-28
B	7	7	7	7	8-11

days, and the second, laid one month later in the season, took only 8 to 10 days. But more significant still, in reference to the influence of temperature upon incubation, are the two females listed in Table 41 which oviposited the last of July and the middle of August. The eggs of the first required but 8 days for developing, and the second only 7 days, the shortest period yet observed for Polyphemus eggs, and the latest in the season also.

SAMIA CALIFORNICA.

We could note the period of incubation of the ova of only 3 members of this species. (See Table 42.)

TABLE 42.

Period of Incubation. Eggs of S. Californica. Sonoma Co., Cal., 1912.

♀ No.	Day's Deposit					Date of 1st Day's Deposit
	1	2	3	4	5	
A	10	10	10	11	10	5-25
B	10	11	11	12	11	5-28
C	12	11	11	11	10	6- 1

Here the period of incubation was from 10 to 12 days for eggs deposited between May 25 and June 5.

PHILOSAMIA CYNTHIA.

We submit below the data on the period of incubation of the eggs of Cynthias from New York and Philadelphia. (See Table 43, 44, 45.)

The New York Cynthias emerged and oviposited earlier than those from Philadelphia. If we compare Tables 43 and 44 a little more closely we will observe that all of the eggs in which the period of incubation was from 10 to 12 days are at the top of the table, or among the eggs deposited June 3 to 12. Again when we look for the eggs which required only 8 or 9 days, we find them under the dates June 13 to 20. Now this first lot spent a period in development from June 3 to 28 inclusive, and the mean temperature for this period of 21 days was 75.8° F. The eggs of the latter lot were in incubation from June 13 to 29, for which period the mean temperature was 83°.

Hence in the Cynthias, as in all the other species here

TABLE 43.

Period of Incubation. Eggs of P. cynthia. New York, 1913.

♀ No.	Day's Deposit				Date of 1st Day's Deposit
	1	2	3	4	
A	11	12	..	..	6- 3
B	12	12	..	..	6- 6
C	12	..	..	..	6- 6
D	13	13	..	..	6- 9
E	14	..	..	..	6- 9
F	11	..	..	..	6- 9
G	12	12	..	..	6-10
H	?	10	10	..	6-11
I	11	?	10	9	6-11
J	9	..	..	..	6-12
K	9	10	..	..	6-12
L	10	10	9	..	6-12
M	11	?	9	9	6-12
N	10	9	10	..	6-13
O	9	9	..	..	6-13
P	9	9	..	..	6-13
Q	9	9	9	..	6-14
R	9	..	..	..	6-14
S	9	9	9	..	6-14
T	9	8	8	..	6-14
U	9	9	..	..	6-14
V	9	9	..	..	6-14
W	8	9	..	..	6-15
Y	9	..	..	..	6-18
Z	9	..	..	..	6-19

considered, it is clear that temperature conditions directly influence the period of incubation, the warmer days tending to accelerate the embryonic development and the cooler days to retard it.

Miscellaneous Data.

BASILONIA IMPERIALIS.

About 12 pupæ of *B. imperialis* were obtained in 1911, but 10 of them were parasitized by a large dipterous insect identified by Mr. Frederick Knab[17] as *Belvasia bifas-*

[17] Through the kindness of Dr. L. O. Howard.

TABLE 44.

Period of Incubation. Eggs of P. cynthia. Philadelphia, Pa., 1913.

♀ No.	1st Day's Deposit	Date of 1st Day's Deposit
A	8	6-17
B	9	6-17
C	10	6-17
D	9	6-17
E	8	6-18
F	9	6-18
G	10	6-19
H	9	6-19
I	9	6-20
J	9	6-20

TABLE 45.

Period of Incubation. Eggs of P. cynthia. New York, 1912.

♀ No.	Day's Deposit			Date of 1st Day's Deposit
	1	2	3	
A	8	8	9	7- 7
B	8	8	8	7-12

ciata Fab. Only one, a normal female, emerged May 28 and lived 8 days. The very evening of its first day it deposited infertile eggs. During its lifetime it laid 186 eggs and retained 10 after its death, making a total number carried of 196 eggs. One of the other chrysalides, when opened some time after all expectation of emergence was gone, was found to contain an adult moth, dead, which for some reason had not been able to effect the proper emergence. It was a female and it must have lived for some time, since 12 eggs had been deposited in this prison house.

PROBABLE TWO-BROODEDNESS OF T. POLYPHEMUS.

All of our Polyphemus adults—and a great number we had from several localities—emerged in May or June and one group emerged in good numbers as early as the last of April. Therefore we were much surprised to take a female on August 11, 1912, which was in good condition. The fact that she laid fertile eggs proves that there must also have been males lurking somewhere this late in the season. With what we know of the longevity of this species, it is impossible to believe this to be one which had emerged in the spring. This species may possibly be double-brooded.

On July 30, 1913, a male Polyphemus was brought to me, apparently in good condition.

INFERTILITY OF POLYPHEMUS EGGS.

Since the Polyphemus were seldom seen in copulo, it was thought that possibly mating might occur for such brief periods that it was only by chance that they could be seen. To test this point, all of the eggs of 25 females of this species which had had ample opportunity for mating were cared for until long past hatching time to see whether, perchance, fertilization had occurred unnoticed. But they all soon shrivelled, and none at all ever hatched. This strongly indicates that mating does not occur for brief intervals on the sly, and also that these females do not lay parthenogenetic eggs.

CROSSINGS.

On June 3 a female Polyphemus mated with a male Cecropia from 6 a. m. to 6 p. m. The female died the next day without ovipositing.

On May 9 a 10-day-old female Polyphemus mated with a male Cecropia. It lived for a few days afterward, and deposited 4 eggs, which proved infertile.

After we found it impossible to get the Prometheas to

mate in 1913, we selected a few cages containing a pair each and introduced into each one a male Cynthia. In four cases out of ten mating occurred, the female Promotheas giving preference to the Cynthia males—or perhaps yielding to their greater animation—and remained in copulo 24, 12, 10 and ? hours respectively. The eggs from these four matings were cared for, but all proved infertile.

June 8 a male Cecropia mated with a female Californica for 10 hours, but the eggs from this crossing also were infertile.

EATING OF EGG SHELLS BY T. POLYPHEMUS.

We found that when the Polyphemus larvæ remained prisoners in the vials in which they had hatched from the egg, they ate parts of many of the egg-shells. We do not know whether it is customary for Polyphemus to eat the shell after having emerged from it, or whether this is done only in the event of scarcity of other food. This practice was not indulged in by the Cynthias, Cecropias or Californicas.

CALLOSAMIA PROMETHEA.

While the Promethea experiments were in progress in 1911, almost every day at about 4 p. m. many free males were attracted to the laboratory by the females, and when they were placed inside the cages they lost very little time before mating. Unlike the Cecropia moth which mates just before dawn, the Promethea is in copulo before sunset, and while the Crecopia remains in mating on an average about 21 hours, this near relative continues for only 4 or 5 hours. The duration of copulation of the 18 pairs was as follows:

Hours in copulo	No. of pairs
Less than 1 hour	2
1 to 2 hours	2
2 to 3 hours	0
3 to 4 hours	4
4 to 5 hours	9
5 to 6 hours	1

In addition to these, many other pairs were left in copulo during the evening, but early the next morning they were found to have severed.

Judging from the short life of the Prometheas, and knowing that the Cecropia moths are mostly monogamous, we might almost assume that this species is also monogamous. From a small number of experiments this seems to be true, and in the case of all of the 24 females which mated, the males were allowed subsequently to remain in the cage. In these cases a second mating was never observed, although the usual period of mating is so short that mating could have occurred at a time when constant watching was impossible.

Some slight interest may be attached to the age of the insects when mating began, to see at how early or how late an age the moths were capable of mating.

Age	Females	Males
6 hours or less	1	1
6 to 12 hours	8	9
12 to 18 hours	1	0
18 to 24 hours	1	0
1 to 2 days	1	1
2 to 3 days	3	0
3 to 4 days	2	1
4 to 5 days	0	0
5 to 6 days	1	0

This table shows that 21 out of the 30 insects of both sexes mated before 24 hours of age.

FLUFFY CECROPIA COCOONS.

In 1911[18] we discussed the nature and abundance of the cocoons of *Samia cecropia.* During the past two years we have made additional observations which are interesting since they substantiate the earlier ones.

During the winters of 1912 and 1913 cocoons were gathered from the River des Pêres region, the same area as

[18] Psyche. 18: 168-170, 1911.

before. In the two lots the proportion of fluffy cocoons to compact ones was as follows:

Year	No. Fluffy	No. Compact	Total
1912-13	108	299	407
1913-14	27	285	312

These figures show that in 1912-13 the baggy cocoons occurred in, approximately, the proportion of 1 to 3 and in the following winter 1 to 10. Our previous work showed the proportion for 1910 to be 1 to 4, and for 1911, 1 to 6.

The sexes, recorded at the time of the emergence of the insects from the fluffy cocoons, were as follows:

Year	Males	Females	Total Observed
1912-13	44	35	79
1913-14	10	14	24

These notes again show that the fluffy cocoons are by no means rare, and that both sexes emerge from them. It is however of peculiar interest that not one fluffy cocoon was found in a lot of 300 cocoons from South St. Louis or the lot of 200 from New York.

We shall have to seek further for the factors controlling this fluffy condition. May it be that it is due to the mere fact that some larvæ are more vigorous than others, this greater vigor being due to the amount of food consumed, and that this greater vigor plus the surplus material in the body may express itself in the large weaving capacity?

DURATION OF PUPAL STAGE IN SAMIA CECROPIA.

Previously[19] we found the pupal period of *S. ceropia* to vary from 312 to 324 days. To this we wish to add the following data:

Sex	Spinning Completed	Emerged	Duration
♀	July 10, 1913	May 23, 1914	317 days.
♂	July 13, 1913	May 23, 1914	314 days.
♀	July 18, 1913	May 25, 1914	311 days.
♂	July 15, 1913	May 27, 1914	316 days.
♀	June 15, 1913	May 23, 1914	342 days.

[19] Psyche. 20: 204, 1913.

THE DURATION OF THE PERIOD OF COPULATION OF TROPAEA LUNA.

Notes were made on the time spent in copulo by four pairs of *T. luna.* One pair remained in copulo 5½ hours, two pairs for 6½ hours, and one pair for 9 hours.

COCOON SPINNING.

The following was the only note that could be made on the spinning of *S. cecropia*:

June 15, at 4 p. m., the cocoon was being commenced; just a few silken threads were spread over the insect. At 6 o'clock the next morning the cocoon covered the entire insect, but was so thin that the green caterpillar could be seen through it. By 4 p. m. the thickness had increased to such an extent that the insect could no longer be seen. So with a sharp knife a slice was cut off the side of the cocoon, making an opening about ½ by ¼ inch. Two hours later this was spun over; hence, the work was evidently still in progress on the inside of the cocoon.

SUMMARY.

1. We find that mating does not significantly lengthen or shorten the life of the males in any of the material observed.

2. In all of the groups studied the unmated females lived longer than the mated females.

3. In Polyphemus as a whole we find the females much longer lived than the males, and for the entire population the mean is much greater for the two southern localities, St. Louis and Augusta, than for the two northern regions, New York and Fall River.

4. In the Prometheas the mean length of life for the whole 1913 Fall River population is much longer than in the 1911 Crêve Coeur lot. Just the reverse exists in the Polyphemus from the two regions.

5. In the Cecropias we find the mean for the St. Louis population to vary from year to year between the extremes of 7.71 and 16.65 days.

6. By keeping Cecropias and Polyphemus in low temperatures the length of life is greatly prolonged.

7. The mean number of eggs carried by the five lots of Polyphemus varies from 198 to 293. In seven lots of Cecropias the mean varies from 195 to 344. The Prometheas show little difference in egg production despite the remote regions (Massachusetts and Missouri) from which they came.

8. In the Cynthias, Cecropias, Lunas and Prometheas the mated females oviposited more nearly completely than the unmated females.

9. A total of 3569 Saturniid cocoons gave 1879 males and 1690 females, or 111 males to 100 females.

10. The males emerged from 1 to 5 days ahead of the females in practically all of the material here considered.

11. We find no relation between the length of time spent in mating and the fertility of the eggs. We have cut the normal length of time of up to 24 or even more hours, to 2 hours without diminishing the fertility of the eggs. There is no relation between the fertility of the eggs and the order of their deposition.

12. The period of incubation of the eggs varies with the climatic conditions.

General Considerations and Conclusions.

In the previous paper we have reviewed fully the theories which have been advanced in an attempt to account for the duration of life. With material representing, as this does, only one small corner of the organic world, we cannot hope to formulate generalizations which would be applicable to all organisms, while to presume to build up entire theories upon the evidence in hand would be to repeat the error which has already

been too often committed of placing generalization before accurate and adequate investigation. It will be quite fitting, however, to take the few conclusive results gleaned from this detailed study and construct from them and around them a scheme which would systematize these factors in their relation to the propagation of this small group.

The very beginning of the adult life shows the simple adaptation to environment which is common to a large proportion of the members of the animal kingdom; their emergence is accelerated by high temperature early in the season or retarded by late cold. While this would be of advantage only to those species which are interested in vegetation, it is interesting to find the condition existing in these animals also which can have no concern for food, excepting for a food-plant upon which to deposit their eggs. In other words, they come out at warm periods, soon to wear themselves out, while they might live much longer if they came out during the colder days, since, as our experiments have shown, cool weather greatly prolongs a quiet life.

In practically all of this material we find the males emerging before the females. This may or may not be due to the fact that the females have the ova to produce; nevertheless, the males are on hand for the function of fertilization when the females appear, and hence this delicate adjustment of life, whatever its rise, is an advantage to the species, while it is of no help that we can now see to the individual.

The homologous length of life of the sexes harmonizes well with the monogamous habit which a large part, at least, of these insects follow. We must acknowledge that it is well for the species that the females are permitted as long a life as they have, in order that they may complete their long task of egg-laying. The males on the other hand have a comparatively long, useless period of life after mating. Since polygamy is known to exist in other species of this family, and in some here dealt with,

may it be that this group is now changing from polygamy to monogamy, and that some characteristics belonging to the former habit have not yet been pruned away?

When we go into the details of the longevity and oviposition of each individual we find many exceptions to this hypothetical principle of longevity as an adaptation for the benefit of the species; some are cut short in the midst of reproduction, while others continue an extended, useless life. But how do we know that this fine balance of longevity and oviposition is not interrupted by some of the details of environment, such as climate, moisture, etc.? May it be that these individuals which do not conform to this principle of the factors of longevity and oviposition are merely the ones which are doomed to probable elimination? Natural selection may now be at work building up these fine adjustments; those which conform to this principle are those which are surviving by the cumulative effects of their complete and abundant reproduction, while those contrary individuals may be the straggling element, always present in any population, undergoing elimination by their own failure to oviposit adequately.

In regard to the portion of the lifetime spent in copulo, it must be felt that here natural selection has not done refined work in having not reduced, during the phylogeny of the species, the time thus spent to a minimum in order to waste none of the allotted precious hours which the female has in which to oviposit.

In most cases we find the mated females depositing a greater per cent. of their eggs than the unmated individuals, while in every population they lived a shorter time than their unmated sisters. This longer life of the unmated female in every case might suggest that Nature is indicating in this way that it is the species rather than the individual that she cares for. Still their lease of life was sufficient to attend to this duty in the propagation of the species. This evidence harmonizes to a degree with Weissmann's theory of longevity being regu-

lated by natural selection for the good of the species, conserving the time which is an advantage to the race and curtailing useless existence.

In short, we must conclude that the longer or shorter life of these insects is due to physiological processes, but one must also admit that, regulating these physiological processes in some way, we have at work natural selection carefully seeing that these insects with aborted mouth parts have all of their ova at hand ready for ovipositing when they emerge from the cocoon, in addition to the proper amount of nutriment to give them sufficient length of life to deposit them, and this even though we know not whether the aborted mouth parts are due to the reserve nutriment or the reserve nutriment is there because of the aborted mouth parts.

Hence it would seem that our major problem is one not of physiological phenomena alone, nor of heredity of longevity alone, but a complex blending of these two factors such as can be raveled only by the analysis of large quantities of data on varied material.

EXPLANATION OF ILLUSTRATIONS.

In Figs. 1-8, the solid lines indicate males and the dotted lines, females.

Plate I.—Fig. 1. The emergence of 240 males and 213 females of *Philosamia cynthia*, New York and Philadelphia, 1913.—Fig. 2. The emergence of 46 males and 54 females of *Telea polyphemus*, St. Louis, 1913.

Plate II.—Fig. 3. The emergence of 101 males and 82 females of *Telea polyphemus*, Fall River, Mass., 1913.—Fig. 4. The emergence of 316 males and 287 females of *Telea polyphemus*, Augusta, Ga., 1913.

Plate III.—Fig. 5. The emergence of 54 males and 50 females of *Callosamia promethea*, Fall River, Mass., 1913.—Fig. 6. The emergence of 123 males and 113 females of *Samia cecropia*, South St. Louis, 1913.

Plate IV.—Fig. 7. The emergence of 76 males and 67 females of *Samia cecropia*, New York, 1913.—Fig. 8. The emergence of 331 males and 320 females of *Samia cecropia*, St. Louis, 1913.

Plate V.—Fig. 9. The emergence of 2237 Saturniid moths in relation to temperature. The solid line indicates all insects observed of both sexes; the broken line denotes temperature.

Issued December 22, 1914.

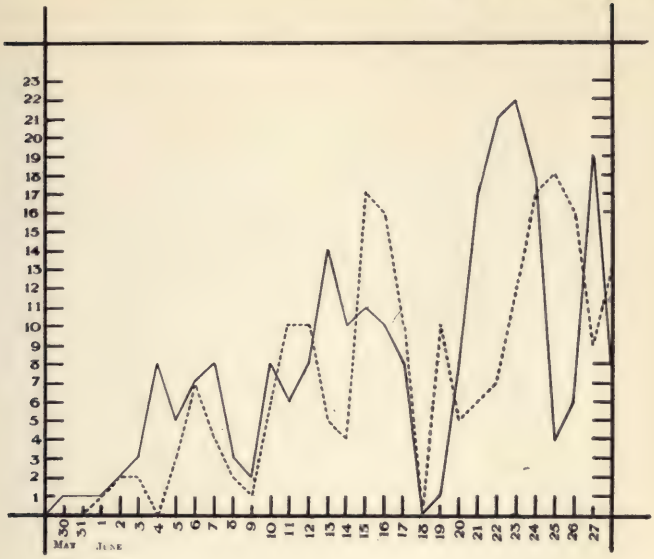

FIG. 1. PHILOSAMIA CYNTHIA.

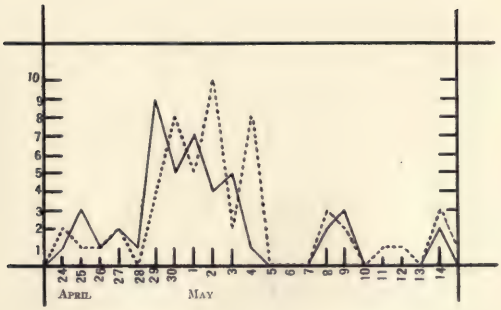

FIG. 2. TELEA POLYPHEMUS.

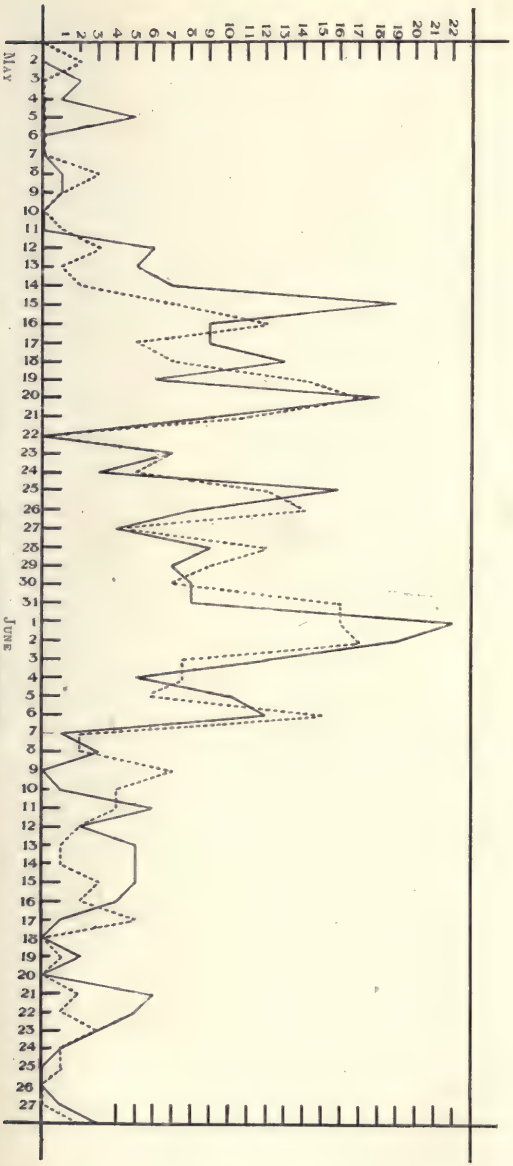

FIG. 4. TELEA POLYPHEMUS.

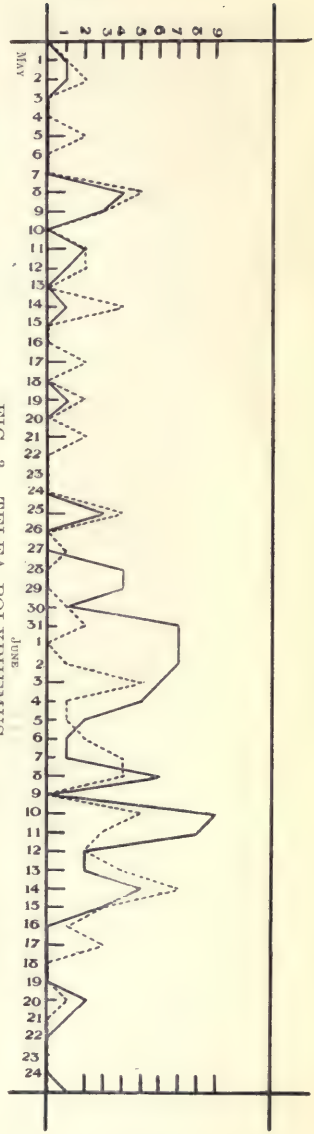

FIG. 3. TELEA POLYPHEMUS.

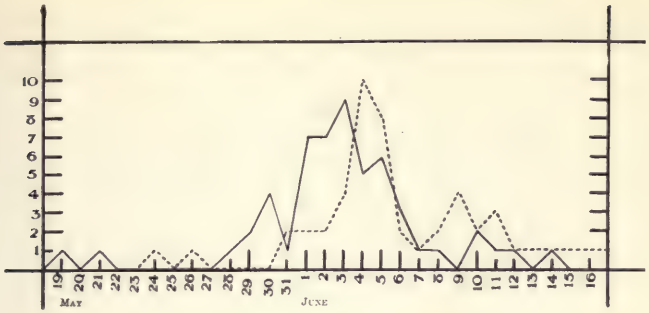

FIG. 5. CALLOSAMIA PROMETHEA.

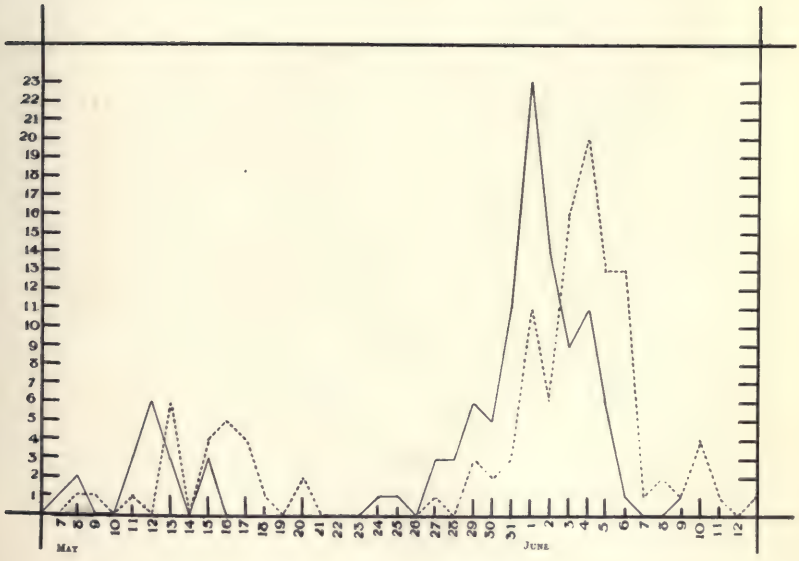

FIG. 6. SAMIA CECROPIA.

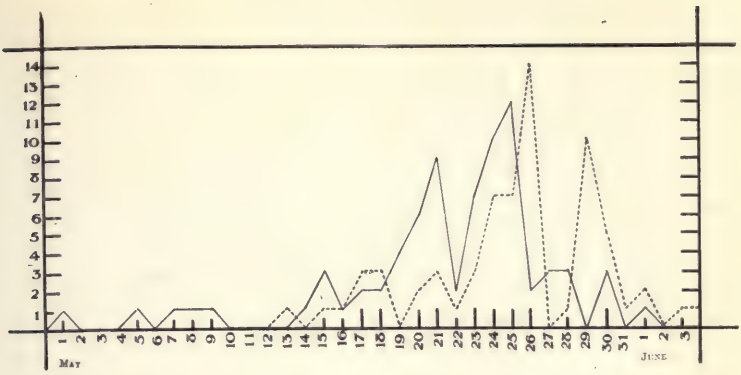

FIG. 7. SAMIA CECROPIA.

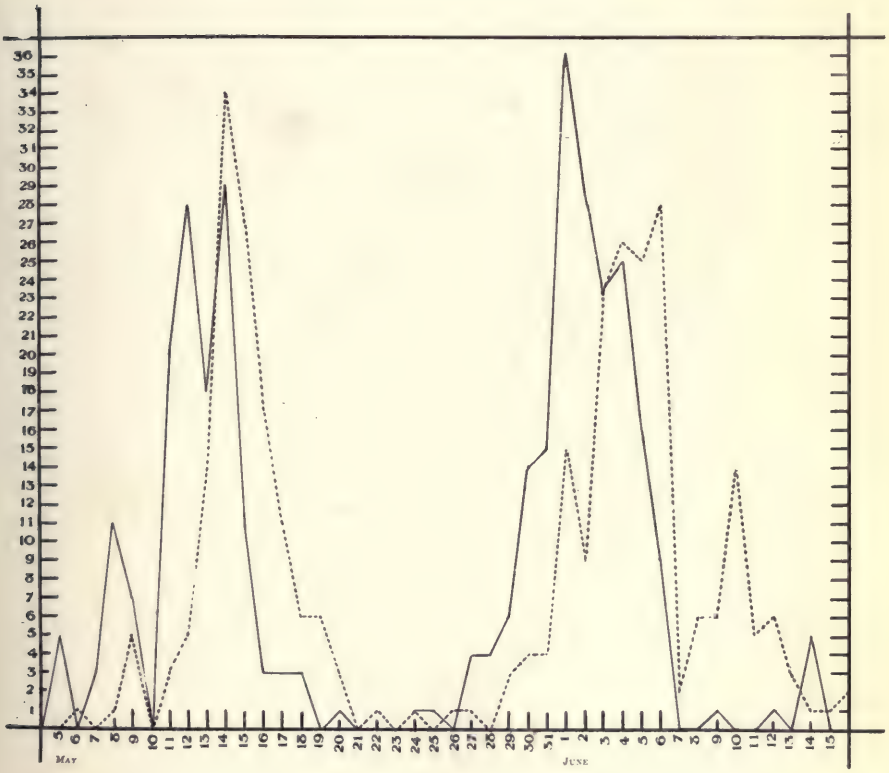

FIG. 8. SAMIA CECROPIA.

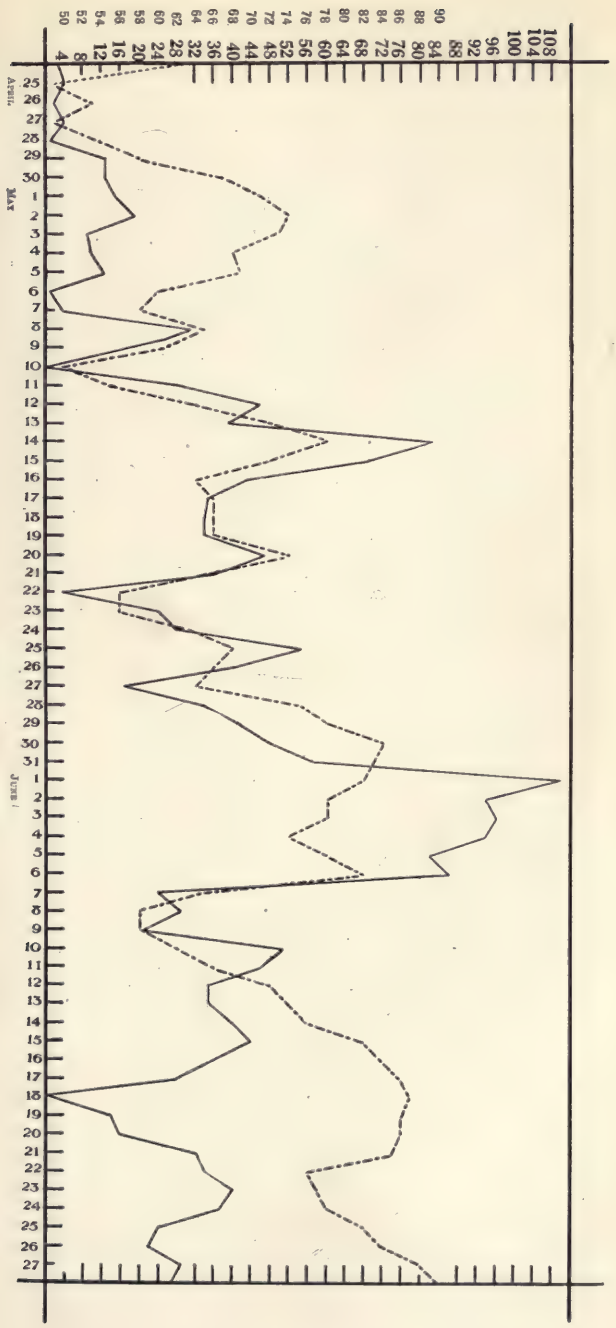

FIG. 9. SATURNIID MOTHS.

THE HISTORY OF SCIENCE IN ST. LOUIS.*

MARY J. KLEM.

The history of science in St. Louis extends back nearly to the time of its founding as one of the first settlements of Upper Louisiana one hundred and fifty years ago. The Jesuit missionaries, the great pioneers of the north and west, were the first white persons to visit the Mississippi Valley and the adjoining country, Father Marquette, the intrepid explorer, having been the first to pass the lonely forest that covered the site of the future city of St. Louis in the year 1673.

Fortunately the early missionaries were men of learning and observation. While they acquitted themselves faithfully of the duties of their calling, they recorded carefully the progress of events around them. The course of the Mississippi and the nature of the country were known to them and to the traders, who jointly with the missionaries carried on the discovery and exploration of the west. By the expeditions of Marquette, Jolliet, La Salle, Hennepin, and others, the Mississippi had been discovered and explored, opening to France the richest and most fertile territory of the new world.

André Michaux,[1] a distinguished French botanist,

* Read before The Academy of Science of St. Louis, May 18, 1914.

[1] Hooker, W. J. On the botany of America. Amer. Jour. Sci. and Arts. I. 9: 266-269. 1825.

Gray, Asa. Notes of a botanical excursion to the mountains of North Carolina. Amer. Jour. Sci. and Arts. I. 42: 2-9. 1842.

Sargent, C. S. Portions of the journal of André Michaux, botanist, written during his travels in the United States and Canada, 1785 to 1796. With an introduction and explanatory notes. Proc. Amer. Phil. Soc. 26: 1-145. 1889.

Thwaites, R. G. André Michaux's travels into Kentucky, 1793-96. Early Western Travels 1748-1846. 3. 1904.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1908: 488-491.

and one of the most interesting and picturesque figures in the annals of botanical discovery in America, may be said to have been the first scientist to visit the vicinity of St. Louis. Before coming to America, Michaux had, in the interests of science, traveled in France, England and the Orient. He came to the United States in 1785 at the request of the French government to study the forest trees and experiment with regard to their transplantation to France. In the course of his travels in North America Michaux explored the mountains of the Carolinas, journeyed through the hazardous swamps and marshes of Florida, visited the Bahamas, crossed the Alleghanies in his search for new plants, and in 1795-96 made a journey from Charleston, S. C., through Tennessee, Kentucky and Indiana, to Kaskaskia, Cahokia and vicinity. Most probably he visited the western shore of the Mississippi. In his "Flora Boreali Americana" he records several species of plants as coming from the Missouri river. This is no positive proof, however, of his having collected west of the Mississippi, as the plants might have been given to him while he was at Cahokia. He mentions St. Louis as a prosperous settlement, but makes no further allusion to it.

Looking back through the vista of years, we find picturesque and interesting incidents shaping the early history of St. Louis, when around it and far to the west stretched an unbroken wilderness into which the white man had scarcely penetrated. One of the central figures in the little French village in the year 1800 was Dr. Antoine François Saugrain—scientist, physician and chemist. Although he was not the first to practice medicine here, he was the most notable of the early representatives of the profession because of his broad learning and scholarly attainments.

Dr. Saugrain[2] was educated as a physician and chem-

[2] Bliss, E. F. Dr. Saugrain's relation of his voyage down the Ohio river from Pittsburgh to the Falls in 1788. Proc. Amer. Ant. Soc. 11: 369-380. 1897.

ist. Entering the service of the king of Spain, he was sent to Spanish America about 1783 to examine the geological formations of the country and its fauna and flora. After a visit to Paris he returned to America and in 1787 explored Kentucky and the country along the Ohio river, writing an interesting account of the adventures that befell him and his companions on this expedition. After enduring almost incredible hardships from fatigue, exposure, hunger, and the attacks of hostile Indians, Dr. Saugrain and his companions reached the Falls of the Ohio. After recovering from wounds he had sustained, the Doctor made an examination of the soil and its natural products, particularly the mineral deposits and salt licks. Proceeding up the Ohio on a flat boat to Fort Pitt, now Pittsburg, he crossed the mountains to Philadelphia, where he was received by Franklin.

Returning to France, Dr. Saugrain remained there until 1792 or 1793, when he sailed again for the United States with a company of French colonists, who located at Gallipolis, Ohio. For various reasons the colonists became dissatisfied and most of them moved elsewhere. Dr. Saugrain went to Lexington, Ky., probably in 1796 or 1797, and the following year visited St. Louis. Being much pleased with the place and the people, he brought his family to live here in 1800.

He seems to have been both popular and successful as a physician, but preferred chemistry to medicine, and devoted all of his leisure time to it. Dr. Saugrain probably had the first laboratory in St. Louis. A contemporary of his says: "Many of my countrymen used to

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Dandridge, N. P. Antoine François Saugrain (De Vigni) "The first scientist of the Mississippi valley." Jour. Amer. Med. Assoc. 43: 2007-2011. 1904.

Goodwin, E. J. Antoine François Saugrain. A history of medicine in Missouri. 19-21. 1905.

Bliss, E. F. Dr. Saugrain's note-books. Proc. Amer. Ant. Soc. 19: 221-238. 1908.

Byars, W. V. The first scientist of the Mississippi valley. A memoir of the life and work of Doctor Antoine François Saugrain. n. d.

come and stare at his doings, which they were half inclined to think had too near a resemblance to the black art. The doctor's little phosphoric matches, igniting spontaneously when the glass tube was broken, were thought by some to be rather beyond mere human power. His barometers and thermometers, with the scale neatly painted with the pen, and the frames richly carved, were objects of wonder."

In his medical practice he depended largely upon herbs which he grew in the garden surrounding his house or gathered in the wild state. The first case of smallpox in St. Louis appeared the year after Dr. Saugrain came. He was an advocate of vaccination, calling attention to its value as a preventive of smallpox and announcing his readiness to vaccinate any one who should apply. He was made post physician under the Spanish lieutenant governor, Don Carlos Dehault Delassus, and, when this section of the country became United States territory, he was reappointed by President Jefferson. Until his death, which occurred in 1820, Dr. Saugrain continued his scientific experimental work and practiced his profession as a frontier physician. He was the first notable representative of scientific investigation in St. Louis and this part of the country.

All the early explorers of the interior of North America dreamed of a passage to the South Sea and of a new road to reach China and Japan with a view to entering into commercial relations with these countries. From the Indians they had learned of a great river flowing into the ocean far away. The theory of a short-cut transcontinental waterway was believed practicable by the French throughout their occupancy of North America. Jolliet and Marquette thought that the Mississippi might flow into the Pacific ocean, but on ascertaining that this was not the case, they looked upon the Missouri river as the one flowing into the Ocean of the West. Several French expeditions were organized to explore the Missouri and some of its lower tributaries, but they ac-

complished very little beside exploring the country for a few hundred miles above its mouth.

In 1783 a proposition was made by Jefferson to George Rogers Clark "for exploring the country of the Missisipi to California," but the expedition was never undertaken. Three years later Jefferson arranged with the adventurous John Ledyard of Connecticut, who had been with Captain James Cook on his third voyage around the world, to penetrate the Missouri river from the west by crossing Europe and Asia to Kamchatka and thence in a Russian trading vessel to Nootka Sound. From there he was to find his way to the sources of the Missouri and descend that stream to the American settlements. This enterprise came to grief when Ledyard was arrested in Kamchatka by agents of the Russian crown. Captain John Armstrong in 1790 attempted to ascend the Missouri under orders from the War Department, but failed because of the hostility of the Missouri Indian tribes. In 1793, Jefferson, as vice-president of the American Philosophical Society—then almost the only organization for the encouragement of scientific study in America—dispatched upon this same mission André Michaux, the distinguished French botanist, who, however, tarried in Kentucky to conduct a French political intrigue, with the result that his project of exploration was abandoned.

When Jefferson became President of the United States he did not forget his early dreams of exploring the Far West, and dispatched Lewis and Clark,[3] the first im-

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[3] Jefferson, Thomas. Biography of Captain Lewis. Anal. Mag. and Naval Chron. 7: 329-333. 1816.

Allen, Paul. History of the expedition under the command of Captains Lewis and Clark. 1814. Reprint New Amsterdam Book Company.

Coues, Elliott. History of the expedition under the command of Lewis and Clark. 1893.

Greely, A. W. Captain Meriwether Lewis and Lieut. William Clark, first trans-continental explorers of the United States. Men of Achievement. Explorers and Travellers. 105-162. 1893.

portant government expedition that was sent out to explore the great unknown mountain regions of the extreme west. This expedition, starting from St. Louis, proceeded up the Missouri river in May, 1804, and, after spending the winter among the Mandan Indians, not far from the present city of Bismarck, North Dakota, resumed the journey in April, 1805. From the head waters of Jefferson Fork they crossed the snow-clad Bitterroot Mountains, and descended the foaming rapids and cataracts of the Columbia river to the Pacific coast. On the return trip Lewis explored the Falls of the Missouri and Maria's river, while Clark and his party descended the Yellowstone to its junction with the Missouri. The final happy arrival of the re-united parties in St. Louis in September, 1806, is one of the familiar events of American history.

From a geographical point of view this expedition was a great and successful achievement, Lewis and Clark having fixed pretty well the positions of the Missouri and Columbia rivers. Every item of information which they secured was a new acquisition to history and science. However, the absence of scientific men from the expedition was seriously felt when the reports were made up from the data at hand. Many discoveries had been made in natural history, but no member of the party being competent to determine their scientific value, Lewis and Clark did not receive the credit for priority of discovery to which they were entitled. The antelope, black-tailed

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Thwaites, R. G. A brief history of Rocky mountain exploration with special reference to the expedition of Lewis and Clark. 1904.

Thwaites, R. G. Original journals of the Lewis and Clark expedition 1804-1906. 1904.

Wheeler, O. D. The trail of Lewis and Clark 1804-1904. 1904.

Smith, W. R. General William Clark, Territorial governor of Missouri. Bull. Washington Univ. Assoc. 4: 46-69. 1906.

Thwaites, R. G. William Clark: Soldier, explorer, statesman. Mo. Hist. Soc. Coll. 2: 1-24. 1906.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1908: 492-493.

deer, mule deer, prairie dog, and grizzly bear were unknown to science until discovered by the Lewis and Clark expedition, the grizzly bear being the most notable discovery made in zoology by Lewis and Clark.

Upon their return to St. Louis the leaders of the expedition began at once to write out their notes for publication. However, both were soon called to high office—Lewis being made governor of the Louisiana Territory, and Clark appointed superintendent of Indian affairs.

Clark made St. Louis his home during the remaining years of his life. He expended much time and effort in establishing an Indian Museum, the first collection of Indian weapons and curiosities in the country, which for a long time was one of the interesting sights in St. Louis to visitors. The Duke of Saxe-Weimar Eisenach, who visited this country in 1825 and 1826, in his "Travels Through North America," gives an extensive description of this interesting museum, from which I quote the following paragraph:

"We then went to see Mrs. Clark, who, through the secretary of her husband, Mr. Alexander, exhibited to us the museum collected by the governor on his travels, and since considerably augmented. Mr. Alexander showed us articles of Indian clothing of different kinds, and various materials. Except the leather, the larger part of these materials were American, or rather entirely European in their origin. A single garment alone was made by the Cherokees of cotton, which was pulled, spun, wove on a loom, made by the Indians, and even dyed blue by them. Besides, several weapons of different tribes, wooden tomahawks, or battle axes; in one of them was a sharp piece of iron to strike into the skulls of their prisoners; another made of elk's horn; bows of elk's horn and of wood; spears, quivers with arrows; a spear head of an Indian of the Columbia river, hewed out of flint; a waterproof basket of the same people, in which cooking can be performed; several kinds of tobacco pipes, especially the calumet, or great pipe of peace. The head of this pipe is cut out of a sort of argillaceous earth, or serpentine; in time of war, the spot where this earth is dug out, is regarded as neutral, and hostile parties, who meet each other at that place, cannot engage in anything inimical against each other. The pipe which the commissioners of the United States use at treaties with the Indians, has a heavy silver head, and a peculiarly handsome ornamented wooden stem. Farther: Mr. Alexander showed us the medals which the Indian chiefs have received at different periods from the Spanish, English and American governments, and the

portraits of various chiefs, who have been at St. Louis to conclude treaties with the governor, who is also Indian agent. Among the remarkable things in natural history, we noticed an alligator, eight feet long; a pelican; the horns of a wild goat, shot by the governor in his tour among the Rocky Mountains; the horns of a mountain-ram and those of an elk; several bearskins, among others, of the white bear; buffalo, elk and skunk, which were sewed together in a robe; skins of martins, ferrets, etc., etc. Moreover, several petrifications of wood, and animal subjects, among others, of elephant's teeth; a piece of rock-salt, tolerably white, yet not shooting in crystals, as the English; various crystals; a large piece of rock crystal; very handsome small agates, which are here taken for cornelians, etc. Among the curiosities, the most remarkable were two canoes, the one of animal-hide, the other of tree-bark; a peace-belt, which consists of a white girdle, set with glass beads two hands breadth wide; farther, snow shoes; nets which are drawn over an oval frame; also the rackets, which they use in playing their game of ball, etc., etc."

Soon after the purchase of Louisiana steps were taken by the government to explore the then unknown wilds of our western country. The name of Zebulon Montgomery Pike[4] will always be associated with those of Lewis and Clark in the history of early explorations beyond the Mississippi. Pike's expedition to the source of the Mississippi and his expedition to the sources of the Arkansas river and the Rocky Mountains of Colorado were the first military and the second governmental explorations which penetrated to any considerable extent our newly acquired territory of Louisiana.

In July, 1805, Pike was ordered to explore and report upon the Mississippi river from St. Louis to its source,

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[4] Pike, Z. M. An account of expeditions to the sources of the Mississippi, and through the western parts of Louisiana, to the sources of the Arkansas and Pierre Jaun rivers, performed by order of the government of the United States during the years 1805, 1806, and 1807; and a tour through the interior parts of New Spain, when conducted through these provinces by order of the Captain General, in 1807. 1810.

Whiting, Henry. Life of Z. M. Pike. Spark's Lib. Amer. Biog. 5: 219-317. 1848.

Greely, A. W. Zebulon Montgomery Pike, explorer of the sources of the Mississippi and Arkansas rivers. Men of Achievement. Explorers and Travellers. 163-193. 1893.

Coues, Elliott. The expeditions of Zebulon M. Pike. 1895.

select sites for military posts, treat with the Indians, and find out what he could about the British traders who still occupied posts in our newly acquired territory. Navigating his boats to the vicinity of the present Little Falls, he proceeded onward by land as far as the mouth of Turtle River. He had an idea that the source of the Mississippi was somewhere near this river, but, owing to the extremely cold weather, he did not push beyond the mouth of the Turtle River and returned to St. Louis in April, 1806.

In July, 1806, Pike left St. Louis on his second expedition to the southwestern part of Louisiana Territory. While near the present site of Pueblo, Colorado, he made an unsuccessful side trip which had for its object the ascent of the since famous peak which bears his name.

Captain Chittenden in his classic history of the American Fur Trade of the Far West says: "It is doubtful if history affords the example of another city which has been the exclusive mart for so vast an extent of country as that which was tributary to St. Louis during the entire period embraced in this work. (1807-1843.) Every route of trade or adventure, to the remote regions of the west centered in St. Louis. The very location at the mouth of the Missouri gave it monopoly of all trade originating in the valley of that stream, whether among the wild tribes of the mountains three thousand miles away, or among the infant settlements which were advancing with slow but sure foot-step along the lower course of the river. The Oregon Trail, which began as an independent line of travel, near the present site of Kansas City, Mo., brought down the tribute from the high mountain sections of the central west, from the interior basin of the Great Salt Lake, and to some extent from the more remote regions on the Pacific slope. In like manner the Santa Fe Trail, which left the Missouri river at the same point as did the Oregon Trail, and was coincident with it for some distance west, carried to and fro that peculiar commerce which long existed with the for-

eign city of Santa Fé, and even with the distant provinces of old Mexico and of southern California."

"It was here that trans-shipment of commerce was made to eastern markets by way of the Mississippi, the Ohio, or the Great Lakes. Warehouses and mercantile establishments arose for outfitting the numberless expeditions to the interior. The government maintained a military post near by, and had here its principal office of Indian affairs for the trans-Mississippi tribes."

"The cause of science has repeatedly acknowledged its indebtedness to the fur trade. Maximilian, Nuttall, Audubon, Nicollet, Catlin, and many others enjoyed facilities for work in that wild country which would have been impossible without the assistance of the trader. This was particularly true of those researches which related to the early life, customs, and tribal history of the Indians; to the fauna and flora of the country; and to the geography of a region which was *terra incognita* when the trader entered it."

The Missouri Fur Trading Company, which owed its success to the great ability and energy of Manuel de Lisa; the Rocky Mountain Fur Company, whose guiding spirit was the brilliant and enterprising General W. H. Ashley; and the American Fur Company, with Pierre Chouteau, Jr., as the capable St. Louis partner of John Jacob Astor, conducting its affairs; these and many other companies too numerous to mention here, were most liberal toward scientific expeditions going up the Missouri and contributed in no small degree to their success.

In 1811 John Jacob Astor[5] launched his famous en-

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[5] Irving, Washington. Astoria; or, Anecdotes of an enterprise beyond the Rocky Mountains. 1836.

Ross, Alexander. Adventurers of the first settlers on the Oregon or Columbia river; being a narrative of the expedition fitted out by John Jacob Astor to establish the "Pacific fur company," with an account of some Indian tribes on the coast of the Pacific. 1849.

Franchère, Gabriel. Narrative of a voyage to the northwest coast

terprise, which contemplated the organization of the fur trade from the Great Lakes to the Pacific and by way of the Sandwich Islands to China and India. He founded at the mouth of the Columbia river a settlement, named Astoria, which was to serve as a central depot. However, this gigantic undertaking was frustrated through a series of disasters and Astoria seized and occupied by the British in 1812. To carry out his scheme, Mr. Astor organized two expeditions, one to go by sea and the other by land along the route followed by Lewis and Clark. The overland expedition left St. Louis under the leadership of Wilson P. Hunt, of St. Louis. Two naturalists availed themselves of this opportunity to visit the upper Missouri, John Bradbury and Thomas Nuttall.

Bradbury[6] had been commissioned in 1809 by the Botanical Society of Liverpool to make some researches into the plant life of the United States. It was then quite the fashion among botanists to collect living plants and cultivate them in gardens, many eventually finding their way to Europe.

Arriving in this country during the summer of 1809, Bradbury, having letters of introduction to Jefferson, visited the latter at Monticello. Acting upon Jefferson's advice, he decided to make St. Louis the center of his explorations instead of New Orleans, as he had originally intended. He arrived in St. Louis on the last day of 1809, and, after the necessary inquiries and prepara-

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of America in the years 1811, 1812, 1813, and 1814; or, The first American settlement on the Pacific. 1854.

Chittenden, H. M. The American fur trade of the far west. 1: 163-246. 1902.

[6] Bradbury, John. Travels in the interior of America in the years 1809, 1810, and 1811. 2nd ed. 1819.

Short, C. W. Transylvania Jour. Med. 34: 12-13. 1836.

Britten, Jas., and Boulger, G. S. Biographical index to British and Irish botanists. 21. 1893.

Thwaites, R. G. Bradbury's travels in the interior of America 1809-1811. Early Western Travels 1748-1846. 5: 1904.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1908: 493-495.

tions, he spent the spring and summer of 1810 making short excursions within a radius of eighty to a hundred miles from St. Louis. In this manner he made an exhaustive study of the natural history of this vicinity, and gathered many living specimens, which he forwarded to Liverpool. Besides studying the plants in the vicinity of St. Louis quite thoroughly, Bradbury explored the coal and lead mines, described the sink holes and fossil remains within twenty miles of the city, and advocated the manufacture of saltpeter from the niter found in the neighboring caves.

Bradbury had intended to remove to the Arkansas river, when, early in 1811, he met at St. Louis the leaders of the overland Astorian expedition and gladly availed himself of their invitation to accompany them. Nuttall,[7] with eagerness, had also embraced this opportunity to gratify his ardent desire for distant travel and his passion for the study of Nature. They journeyed with the traders for eighteen hundred miles to the fur trading station among the Mandans. During their journey they experienced many hardships and were in constant danger of losing their lives, being pursued and robbed by the Indians. Bradbury fell into their hands and only saved his life by taking his watch to pieces and distributing the works among the Indians. Nuttall, overcome by fatigue and hunger, and driven to despair in the wilderness, laid down and would inevitably have died, had he not been found by a friendly Indian, who placed him in his canoe and rowed him down the Missouri river to the

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[7] Short, C. W. Transylvania Jour. Med. 34: 14-16. 1836.
Durand, Elias. Proc. Amer. Phil. Soc. 7: 297-315. 1860.
Meehan, Thos. Gardeners' Month. 2: 21-23. 1863.
Britten, Jas., and Boulger, G. S. Biographical index of British and Irish botanists. 129. 1893.
Pop. Sci. Month. 46: 689-696. 1895.
Youmans, W. J. Pioneers of Science in America. 205-214. 1896.
Harshberger, J. W. Botanists of Philadelphia. 151-159. 1899.
Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 52-57.

first white settlement. Nuttall returned to Philadelphia with many and various species of plants and seeds, with many valuable specimens of minerals and other objects of natural history.

Bradbury, upon his return to the Arikara village, found the Astorians in active preparation for their journey across the continent by land. He was invited to accompany them to the coast, but on account of his large collections and the uncertainty of obtaining tranportation by sea, he preferred to return to St. Louis with Henry M. Brackenridge in one of the boats belonging to Manuel Lisa, a prominent fur trader of St. Louis.

Having finally returned to Liverpool in 1815, Bradbury published in 1817 a book on his Travels in the Interior of America, 1809-1811. In the preface to the second edition of 1819 it is stated that Mr. Bradbury has taken up his permanent residence in St. Louis. He was visited by the members of Long's Expedition at his home at Sulphur Springs, in the valley of the River des Peres, not far from what is now Cheltenham. His name is given in the city directory for 1821, but it does not appear in subsequent issues and no further information has been obtainable of his whereabouts.

Another naturalist who visited this section of the country early in the nineteenth century was Henry Rowe Schoolcraft,[8] a conspicuous figure among the scientists of the early part of the century. To him we are indebted for the first account of the geological formations of the great valley beyond the Alleghanies and of its mineral wealth and resources. We are also indebted to him for the discovery of the source of the Mississippi river in Itasca lake. For many years, beginning with 1817, he

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[8] Henry Rowe Schoolcraft. Annals of Iowa. 1865: 498-505.
Henry Rowe Schoolcraft. Amer. Geol. 5: 1-9. 1890.
Youmans, W. J. Henry Rowe Schoolcraft. Pioneers of Science in America. 300-310. 1896.
Williams, M. C. Henry R. Schoolcaft. Mo. Hist. Soc. Coll. 2: 45-47. 1903.

stirred up interest in natural history from one end of the land to the other, and after his settlement in the west he was readily accessible to scientists and travelers.

Schoolcraft was a geologist, who did considerable special work in mineralogy, then an almost unknown science in the United States, and studied the phenomena of meteorology. He was a great traveler, always on errands of scientific interest, an enthusiastic student of archæology, and was particularly known as an investigator and standard authority in all that pertained to the ethnology of the North American Indian.

In 1817 he decided to study the topography, geology and mineralogy of the Mississippi Valley, as well as its ethnology. This offered great opportunities on account of its curious mounds, its antiquities and existing Indian tribes. The localities he explored were principally in Missouri, and Schoolcraft's name is indelibly linked with the natural history of this state. From Pittsburg he journeyed down the Ohio river to its mouth and up the Mississippi to St. Louis, traveling at the rate of five or six miles a day. While the men poled the barges he explored the country west of the Mississippi, which is noted for its mines. It took him about three weeks to reach Herculaneum, and for the remaining thirty miles to St. Louis he tramped through the woods and over the hills, noting in his journal every peculiar topographical feature. Schoolcraft was greatly pleased with St. Louis, being particularly interested in the private museum of Governor Clark.

He did not stay very long in the city, but moved to Potosi, which he made the center of his investigations in the mining regions of that district. Having made a very minute mineralogical study of the region, and wishing to ascertain its geological connection with the Ozarks and neighboring mountains, he explored the southwestern part of Missouri and Arkansas.

After 1811 no scientific expeditions penetrated the Far

West until 1819-20, when Major Stephen H. Long[9] and his corps of scientists made their famous explorations.

From the reports of trappers, topographers had begun to suspect that the Platte river might possibly flow from some pass in the center of the Rockies, more accessible and more practicable than the round-about and difficult path of Lewis and Clark and the Astorians to the Pacific. In 1819 Major Stephen H. Long, a topographical engineer, who had made trips to the Red and Washita rivers in 1817-18, was sent by President Monroe to discover, if possible, this desirable South Pass, and on his return to make an attempt to determine the source of the Red river.

As originally planned, the scientific observations were to be conducted by a company of specialists under the command of Major Long. Among his associates were Dr. William Baldwin,[10] the botanist, who terminated his labors and his life on this expedition at Franklin, Mo.; Dr. Edwin James[11], Dr. Baldwin's successor, who is best

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[9] Chittenden, H. M. The American fur trade of the far west. 2: 562-587. 1902.

Thwaites, R. G. Edwin James's Account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819, 1820. By order of the Hon. J. C. Calhoun, Secretary of War, under the command of Maj. S. H. Long, of the U. S. Top. Engineers. Early Western Travels 1748-1846. 14-17. 1904.

[10] Darlington, Wm. Reliquiae Baldwinianae. 1-346. 1843.

Redfield, John. Dr. William Baldwin. Bot. Gaz. 8: 233-237. 1883.

Harshberger, J. W. William Baldwin. Botanists of Philadelphia. 119-125. 1899.

Thwaites, R. G. Edwin James's account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819, 1820, by order of the Hon. J. C. Calhoun, Secretary of War, under the command of Maj. S. H. Long, of the U. S. Top. Engineers. Early Western Travels 1748-1846. 14: 39. 1904.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1908: 495-497.

[11] Parry, C. C. Dr. Edwin James. Amer. Jour. Sci. and Arts. II. 33: 428-430. 1862.

Thwaites, R. G. Edwin James's account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819, 1820, by order of the Hon. J. C. Calhoun, Secretary of War, under the com-

known among scientific men in this counutry as the botanist and historian of this expedition, and who made the first ascent to the summit of Pike's Peak on July 14, 1820; Dr. Thomas Say,[12] the zoologist; and Dr. A. E. Jessup,[13] the gelogist.

While this expedition did not accomplish either of the great objects for which it was sent out—the discovery of the sources of the Platte and the Red rivers—the work of the scientists was, however, of great value, inasmuch as it added to our knowledge of a part of the country which was hitherto but imperfectly known through hunters and traders. This applies especially to the discoveries made in natural history and ethnology.

Before leaving St. Louis, Long's party made some local investigations. Dr. Say examined some of the sink holes around St. Louis, descending into one of them for the purpose of ascertaining the mean temperature below the surface of the earth. On the grassy plains to the west of St. Louis Dr. Baldwin found many beautiful plants, among them *Aristolochia sipho* (the Dutchman's pipe), *Cypripedium spectabile and parviflorum* (Lady slippers), *Lilium catesbeiana* (Red lily), *Triosteum perfoliatum* (Horse gentian), *Clematis virna* (Virgin's bower, and *Tradescantia virginica* (Spiderwort). Dr. Say went down the river to the mouth of the Meramec and up that stream about fifteen miles. He had been told of the discovery of many graves in that locality said to contain skeletons of a diminutive race. In one

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mand of Maj. S. H. Long, of the U. S. Top. Engineers. Early Western Travels 1748-1846. 14: 40. 1904.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1908: 497-498.

[12] Youmans, W. J. Thomas Say. Pioneers of Science in America. 215-222. 1896.

[13] Thwaites, R. G. Edwin James's account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819, 1820, by order of the Hon. J. C. Calhoun, Secretary of War, under the command of Maj. S. H. Long, of the U. S. Top Engineers. Early Western Travels 1748-1846. 14: 40. 1904.

of the graves a skull without teeth had been found, giving rise to another local theory that these prehistoric residents of the Meramec had jaws like a turtle. Dr. Say found that the graves were walled in and covered with flat stones. He opened several of them and saw that the bones were of ordinary size, seemingly having been buried after the flesh had been separated from them, according to the custom of certain Indian tribes. The skull of the turtle-like jaw was that of an old man who had lost his teeth.

They also devoted a great deal of time to the Indian mounds of St. Louis, locating twenty-seven along a line leading north of the city and on what they called the second bank of the river. Each of these mounds was measured with care. On the Illinois side of the river, within five miles from the river bank opposite St. Louis, they found seventy-five mounds. Their report reads as follows:

"Tumuli, and other remains of the labors of nations of Indians that inhabited this region many ages since, are remarkably numerous about St. Louis. Those tumuli immediately northward of the town, and within a short distance of it, are twenty-seven in number, of various forms and magnitudes, arranged nearly in a line from north to south. The common form is an oblong square, and they all stand on the second bank of the river."

"In the prairies of Illinois, opposite St. Louis, are numbers of large mounds. We counted seventy-five in a course of a walk of about five miles, which brought us to the hill a few years since occupied by the monks of La Trappe. This enormous mound lies nearly from north to south, but it is so overgrown with bushes and weeds, interlaced with briers and vines, that we were unable to obtain an accurate account of its dimensions."

In 1830 and 1831 George Catlin,[14] the well known In-

[14] Notes relative to George Catlin. Ann. Rept. Smith. Inst. 1872: 53-54. 1873.

Donaldson, Thos. The George Catlin Indian gallery in the U. S. National Museum (Smithsonian Institution) with memoir and statistics. Rept. U. S. Nat. Mus. 1885.

Matthews, Washington. The Catlin collection of Indian paintings. Ann. Rept. U. S. Nat. Mus. 1890: 593-610. 1891.

Youmans, W. J. George Catlin. Pioneers of Science in America. 336-346. 1896.

dian painter, was in St. Louis, accompanying Clark, Superintendent of Indian Affairs, on his missions to close treaties with the Winnebago, Shawnee, Sac, Fox, and Kansas Indians. In these interviews he began the series of his Indian paintings. In 1832 he painted the portraits of Black Hawk, White Cloud, and their warriors, who were prisoners of the Black Hawk War at Jefferson Barracks. In the same year he ascended the Missouri river to Fort Union, at the mouth of the Yellowstone, and returned to St. Louis in a canoe with two men, steering his frail craft the whole distance of two thousand miles with his own paddle. On this trip he visited and painted ten tribes, among them the Mandans, to whom he devoted more time and labor than to any other Indian tribe in North America.

Catlin's work was undertaken in a truly scientific spirit, and resulted in leaving to the world the fullest and most varied records in pictures and written descriptions of the aboriginal tribes as they appeared before their customs and ideas had been modified by contact with white civilization. In the preface to his catalogue he says: "Having some years since become fully convinced of the rapid decline and certain extinction of the numerous tribes of the North American Indians, and seeing also the vast importance and value which a full pictorial history of these interesting but dying people might be to future ages—I set out alone, unaided and unadvised, resolved (if my life should be spared), by the aid of my brush and my pen, to rescue from oblivion so much of their primitive looks and customs as the industry and ardent enthusiasm of one lifetime could accomplish, and set them up in a gallery unique and imperishable, for the use and benefit of future ages."

After many vicissitudes his collection was seized in London for debt, but Mr. Joseph Harrison, Jr., of Philadelphia, advanced the funds necessary to release it, and took the collection as security. It was stored until 1879, when so much of it as had escaped the ravages of time

was presented by Mr. Harrison's widow to the Smithsonian Institution, where it now is as the George Catlin Indian Gallery of the United States National Museum.

In the early part of the nineteenth century the chief object of every ambitious and thoughtful explorer was to secure for the world as complete a catalog of its plants and animals as possible. The still unknown regions of the New World, particularly those of the trans-Mississippi country with their primitive races, which had not yet been contaminated by civilization, their beasts of prey, brilliantly plumed birds and unkonwn plants, offered a splendid field for research. Even persons of royal lineage heard this call of the new world. Alexander Philip Maximilian,[15] Prince of Wied-Neu-Wied, visited North America in 1833, making a scientific exploration of the trans-Mississippi region. He was accompanied by a young Swiss artist, Charles Bodmer, who painted primitive landscapes and portraits of the aborigines.

Tarrying briefly in Boston, New York and Philadelphia, he visited the Moravians at Bethlehem and spent the winter of 1832-33 on the banks of the Wabash, in the communistic settlement of Robert Owen, where he found a good library of Americana and of natural history. Early in 1833 he made the journey to the mouth of the Ohio and up the Mississippi, arriving in St. Louis before the departure of the usual spring caravans of the western fur traders.

While in St. Louis Maximilian was invited by General Clark to accompany a deputation of Sauk and Fox Indians, headed by Keokuk, on a visit to the imprisoned chief, Black Hawk, at Jefferson Barracks. He was particularly interested in the many species of birds and butter-

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[15] Thwaites, R. G. Travels in the interior of North America. By Maximilian, Prince of Wied. 1843. Early Western Travels 1748-1846. 22-24. 1904.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 50-52.

flies he noted and the characteristic fossil crinoids of this region. He described carefully the mounds in St. Louis and crossed the river to visit those in Illinois, particularly Cahokia Mound.

Instead of joining one of the annual fur trading caravans of the Rocky Mountain Fur Company, as he had planned, Maximilian, on the advice of General Clark, took the American Fur Company's annual steamboat to their trading posts on the Missouri. At Fort Clark, the company's Mandan post, the German visitor attended various ceremonies, dances and feasts, took portraits of the chiefs, and studied the manners and customs, and myths and superstitions of this vanishing race.

About 1830 St. Louis began to feel the effects of the Oregon immigration movement, and among the earliest leaders was Nathaniel Jarvis Wyeth,[16] who conducted two expeditions to the Far West. His project was to organize a trading company to do business in the valley of the Columbia river and its tributaries, his plan being to furnish supplies to his colonists and ship his products by ocean vessels sailing to and from the Columbia. He believed that by this method he could reach the country beyond the mountains far more cheaply than by way of St. Louis.

On his second expedition Wyeth was accompanied by two scientists—Thomas Nuttall and John K. Townsend,[17]

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[16] The correspondence and journals of Captain Nathaniel J. Wyeth, 1831-6. Sources of the History of Oregon. 1. 1899.

Young, F. C. The Oregon trail. Oregon Hist. Soc. Quart. 1: 339-370. 1900.

Drake, S. A. Nathaniel J. Wyeth. Oregon Hist. Soc. Quart. 1: 66-70. 1900.

Chittenden, H. M. The American fur trade in the far west. 1: 434-456. 1902.

Thwaites, R. G. Wyeth's Oregon, or, A short history of a long journey. Early Western Travels 1748-1846. 21: 1904.

[17] Thwaites, R. G. Narrative of a journey across the Rocky mountains to the Columbia river, and a visit to the Sandwich Islands, Chili, etc., with a scientific appendix. 1839. Early Western Travels 1748-1846. 21. 1904.

who travelled under his protection as far as the Snake river. Townsend was a well known Phliadelphia physician and naturalist, who had long been anxious to explore the far western country in the interests of science. Hearing from his friend, Nuttall, that he was preparing to join an expedition across the continent, Townsend made arrangements to accompany him, and obtained from the American Philosophical Society and the Academy of Natural Sciences of Philadelphia a commission to search for birds on their behalf.

Arriving at St. Louis on the evening of March 24, 1834, they started on their tour on the 29th. At Florissant they observed great numbers of the brown or sandhill crane (*Grus canadensis*) flying above them; some flocks were so high as to be entirely beyond their vision, although they could distinctly hear their harsh and grating cries. They had seen several flocks of the same cranes while ascending the Mississippi several days before. At St. Charles they saw quite a number of birds, among them the large pileated woodpecker (*Picus pileatus.*) On March 31st they observed large flocks of wild pigeons and thousands of golden plovers, the ground being often literally covered with them for acres. The prairie hen or pinnated grouse was also represented in large numbers. The two scientists joined Wyeth at Booneville, Mo., covering the distance from St. Louis to that point on foot.

About 1836 J. N. Nicollet,[18] a distinguished French astronomer and geographer, came to this country on a

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[18] Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi river made by J. N. Nicollet, while in the employ under the Bureau of Topographical engineers, Feb. 16. 1841. 1843.

Rogers, H. D. Jean N. Nicollet. Amer. Jour. Sci. and Arts. I. 47: 139. 1844.

Sibley, H. H. Memoir of Jean N. Nicollet. Minn. Hist. Coll. 1: 183-195. 1850-56.

Frémont, J. C. Memoirs of my life. 1: 30-72. 1887.

Winchell, N. H. Jean N. Nicollet. Amer. Geol. 8: 343-352. 1891.

scientific tour. His intention was to explore the Alleghany Mountains to the Southern States; to ascend the Red, the Arkansas and the Missouri rivers, and to examine the Mississippi river from its mouth to its source. During the five years he was engaged in these excursions he made numerous observations, calculated to serve as the foundation for an astronomical and physical geography of this country. In connection with this work he also studied the customs, habits, and languages of the several Indian nations that occupied the vast territory which he explored.

The government arranged with Nicollet to extend his survey south and west of the country which he had already explored. On this survey he was accompanied by John C. Frémont, as assistant, and Charles Geyer,[19] a St. Louis botanist.

While preparing for this expedition he was ably assisted by Dr. George Engelmann and the Jesuit Fathers of St. Louis University. He acknowledged this assistance in the following words:

"All these altitudes, with the exception of what is south of the entrance of the Ohio, have been referred to the ordinary low water in the Mississippi at St. Louis. The absolute height of the barometer at this point was not known; and my addressing myself to the reverend fathers, the Jesuits, and engaging them in making meteorological observations, was the first approach toward obtaining it. The late Rev. Mr. Van Sweevelt charged himself with the task, receiving 19 months of observations, made 5 times a day, through the years 1835 and 1836. When Mr. Van Sweevelt was obliged to discontinue his observations, I had the good fortune to find a successor, not less zealous, in Dr. Engelmann, who followed these observations with a regularity that was unlooked for from a person so occupied, otherwise with professional engagements. The years to which these observations refer are 1837, 1838, 1839, and some months of 1840. As for some time the members of the Western Academy have undertaken a regular system of meteorological observations, we have reason to

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[19] Karl Andreas Geyer. Chronik des Gartenwesens. 3:185-187. 1853.
Reichenbach, H. G. Karl Andreas Geyer. Kew Garden Misc. 7: 181-183. 1855.
Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 124-125.

hope that, in some years from this, there will be a definite clearing up of this point."

Nicollet was the first explorer who made much use of the barometer for obtaining the elevation of our great interior country above sea level. He was a most industrious, indefatigable, earnest, and accurate explorer, and the map which embodied the results of his labors was, in the opinion of General G. K. Warren, "one of the greatest contributions ever made to American geography."

In 1839 Dr. Adolph Wislizenus[20] of St. Louis left on a scientific tour with the annual caravan of the fur traders. Wislizenus traveled up the Kansas river to the Platte, along the Platte to Fort Laramie, over the Black Hills and the Wind River Mountains to the Green river rendezvous, and finally to Fort Hall on the Snake river. Upon his return to St. Louis he published the results of this journey under the title of "Ein Ausflug nach den Felsen-Gebirgen im Jahre 1839," an English translation of which, prepared by a son of Dr. Wislizenus, was published by the Missouri Historical Society two years ago.

In 1842 John C. Frémont,[21] through the efforts of Senator Thomas H. Benton of Missouri, was selected by

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[20] Memoir of a tour to northern Mexico connected with Col. Doniphan's expedition, in 1846 and 1847. By A. Wislizenus, M. D. 1848.

Körner, Gustav. Das deutsche Element in den Vereinigten Staaten von Nordamerika 1818-1848. 333-337. 1880.

In memoriam Adolph Wislizenus, M. D. Trans. Acad. Sci. St. Louis. 5: xxxvii-xxxviii. 1889.

Engelmann, G. J. Frederick Adolphus Wislizenus. Trans. Acad. Sci. St. Louis. 5: 464-468. 1892.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 244-246.

Wislizenus, F. A. A journey to the Rocky mountains in the year 1839. By F. A. Wislizenus, M. D. Translated from the German with a sketch of the author's life. 1912.

[21] Bigelow, John. Memoir of the life and public service of John Charles Frémont. 1856.

Upham, Charles Wentworth. Life, explorations, and public services of John Charles Frémont. 1856.

President Harrison to explore the South Pass "in aid of and auxiliary to the Oregon emigration." Leaving St. Louis, well equipped with scientific instruments and with Kit Carson as guide, Frémont examined the South Pass of the Rocky Mountains and ascended the highest peak of the Wind River Mountains, which is now called Frémont's Peak. In the course of his journey he experienced much hardship, being frequently attacked by Indians, but made many contributions to our knowledge of the Rockies, returning with a vast amount of useful observations and many hundreds of specimens in botany and geology.

In the summer of 1843 he conducted a second expedition from St. Louis up the valley of the Platte river and through the South Pass, explored the Great Salt Lake, making important discoveries in geography. From Fort Vancouver he journeyed to the Sacramento river, suffering severely from hunger and cold. Returning through the Great Basin and the South Pass, he finally reached St. Louis again late in 1844.

In the spring of 1845 Frémont set out on his third expedition to explore that section of the Rocky Mountains which gives rise to the Arkansas, the Rio Grande del Norte of the Gulf of Mexico, and the Rio Colorado of the Gulf of California; to complete the examination of the Great Salt Lake and its interesting region; and to extend the survey west and southwest to the Cascade and Sierra Nevada Mountains.

Frémont undertook a fourth expedition in 1848, at his own expense, assisted by public spirited citizens of St. Louis, to explore a route for a railway from St. Louis to California. He left St. Louis October 9, 1848, proceeding by way of the Kansas river to the head-waters

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Frémont, J. C. Memoirs of my life. 1887.

Greely, A. W. John Charles Frémont, the Pathfinder. Men of Achievement. Explorers and Travellers. 212-239. 1893.

Dellenbaugh, F. S. Frémont and '49. 1914.

Sabin, E. L. Kit Carson days. (1809-1868.) 1914.

of the Colorado and across the Wahsatch Mountains into California.

In the spring of 1843 John James Audubon,[22] the ornithologist, spent several weeks in St. Louis, preparing for a trip up the Missouri in the steamboat of the American Fur Company. While here he was entertained by the members of the Western Academy of Natural Sciences, being elected an honorary member of that organization April 17, 1843.

In 1846 Wislizenus again left St. Louis, this time with the intention of making a tour through northern Mexico and Upper California. His principal object was to study the topography and natural history of that country. He made a large collection of rare and theretofore unknown plants, examined the geological formation of the rocks, visited many mines, and analyzed some of the ores. He made barometrical observations to ascertain the elevation above the sea level, compiled meteorological tables, and gathered data relating to the number, industry, manners, customs, and previous history of the inhabitants of the country through which he passed.

Shortly after he had started on this expedition, which he had outfitted from his private means, the war with Mexico broke out, and interfered with his plans. He was detained many months as he states "in a very passive situation" by the Governor of the State of Chihuahua. After the arrival of American troops he joined the medical department of the Army and returned to the United States by way of Monterey.

Although the results of his researches must have been very unsatisfactory to him, Wislizenus had the satisfaction of having been one of the first scientific pioneers

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[22] St. John, H. R. Audubon. 1856.
Pierce, B. K. Audubon's adventures. 1890.
Youmans, W. J. John James Audubon. Pioneers of Science in America. 152-166. 1896.
Audubon, M. R. Audubon and his journals. 1897.
Burroughs, John. John James Audubon. 1902.

who explored a great part of northern Mexico and the southwestern United States. At the instance of Senator Benton, the United States Senate ordered printed five thousand copies of his journal, together with the accompanying tables and maps. Dr. Engelmann worked up the flora from the specimens collected by Dr. Wislizenus on this trip.

From 1844 to 1860 more than twenty expeditions were sent out by the government with the object of determining the best route for a railroad to the Pacific coast. The information obtained through these expeditions was published by the government in a large series of maps and reports.[23] For the later expeditions under King, Wheeler, Powell, Hayden, and others, gotten up for the purpose of studying the topography, geology, and natural history of the country, St. Louis was no longer the point of departure and return, on account of the advent of railroads west of the Mississippi river.

From the earliest days the history of science in St. Louis has been more or less intimately connected with the institutions for higher education in the city. The oldest institution of this character is the St. Louis University,[24] founded in 1818, three years before Missouri was admitted to statehood, when the Right Reverend Louis William Du Bourg, Bishop of Louisiana, opened the St. Louis Academy, which grew into the St. Louis College, and finally developed into the St. Louis University. The university charter was granted by a special act of the legislature in 1832. St. Louis University is

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[23] Warren, G. K. Memoir to accompany the map of the territory of the United States from the Mississippi river to the Pacific Ocean, giving a brief account of the exploring expeditions since A. D. 1800. Reports of explorations and surveys, to ascertain the most practicable and economical route for a railroad from the Mississippi river to the Pacific Ocean. 11. 1859.

[24] Hill, W. H. Historical sketch of the St. Louis University. 1879.

Fanning, W. H. W. Historical sketch of the St. Louis University. Bull. St. Louis Univ. 4: 4. 1908.

probably the oldest university west of the Mississippi river, and certainly the oldest in the Louisiana Purchase Territory.

Among the early professors was Father De Smet, who became so illustrious in succeeding years as a missionary among the Indians of the Rocky Mountains. A copy of Father De Smet's map of the Columbia river and the Puget Sound region is among the historical treasures of the university. The original map was presented to President Polk by Father De Smet during the international controversy with the British Government about the northwestern boundary. This map was of great importance as evidence in the settlement of this vexatious question.

In 1836 the closing of a college in France gave St. Louis University the opportunity to purchase quite an assortment of chemical and physical apparatus of great value. This gave the university a high scientific rank, which it has maintained to the present time. In 1854 an observatory was added, where some of the best work of the Fathers has been done. Since 1889 the university has maintained a post-graduate School of Philosophy and Science, and in 1908 added a School of Advanced Science, the object of which is to train scientific specialists.

As early as 1835 the President of the University held a consultation with the Medical Society of St. Louis relative to the establishment of a medical faculty at the university. Dr. William Beaumont,[25] famous for his observations on the process of digestion, was a member of the first medical faculty of the university. This department does not seem to have made much progress up to the year 1842, when it was reorganized, but was very successful from that time on, especially after the accession to the

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[25] Reyburn, Thos. Memoir of the late Dr. Beaumont. St. Louis Med. Surg. Jour. 12: 127-139. 1854.

Osler, Wm. William Beaumont. A pioneer American physiologist. Jour. Amer. Med. Assoc. Nov. 1902.

Myer, J. S. Life and letters of Dr. William Beaumont. 1912.

faculty of Dr. Charles Alexander Pope[26] in the year 1843, who was later on dean of the faculty. Dr. Pope enjoyed such popularity among the people that the medical school was usually referred to as "Pope's College." Through his influence his father-in-law, Col. John O'Fallon, erected a new building for the medical college in 1850, at Seventh and Myrtle streets, the latter now Clark avenue. On the faculty were also Dr. Daniel Brainard, a distinguished author and one of the most prominent surgeons of the northwest; Dr. Moses L. Linton,[27] founder of the "St. Louis Medical and Surgical Journal"; Dr. Wm. McPheeters,[28] Dr. Linton's associate; and Dr. Hiram A. Prout.[29]

It is one of the glories of the old medical faculty of St. Louis University that the "St. Louis Medical and Surgical Journal" was founded and edited by its professors. The "St. Louis Medical and Surgical Journal"

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[26] Biographical sketch of Prof. Charles A. Pope. St. Louis Med. Surg. Jour. II. 3: 1-6. 1866.

Death of Professor Charles A. Pope. St. Louis Med. Surg. Jour. II. 7: 384. 1870.

Chesney, J. P. Charles A. Pope. Trans. Amer. Med. Assoc. 29: 741-747. 1878.

Outten, W. B. Characterization of Charles A. Pope. Tri-State Med. Jour. 3: 46. 1896.

Goodwin, E. J. A history of medicine in Missouri. 38-39. 1905.

Outten, W. B. Dr. Charles Alexander Pope. Glimpses of early St. Louis medical history. Medical Fortnightly 33-34: 253-256. 1908.

[27] Biographical sketch of Prof. M. L. Linton. St. Louis Med. Surg. Jour. II. 4: 1-8. 1867.

Death of M. L. Linton. St. Louis Med. Surg. Jour. II. 9: 383-387. 1872.

Chesney, J. P. M. L. Linton. Trans. Amer. Med. Assoc. 29: 697-701. 1878.

Sawyer, A. L. M. L. Linton. St. Louis Med. Surg. Jour. 64: 52-57. 1893.

Outten, W. B. Dr. M. L. Linton. Glimpses of early St. Louis medical history. Medical Fortnightly. 33-34: 173-174. 1908.

[28] W. M. McPheeters. St. Louis Med. Surg. Jour. 64: 112-116. 1893.

W. M. McPheeters. Med. Rec. New York. 67: 463. 1905.

Goodwin, E. J. A history of medicine in Missouri. 234-236. 1905.

[29] Holmes, N. L. Hiram A. Prout. Trans. Acad. Sci. St. Louis. 2: 178-179. 1862.

was one of the first prominent medical publications, not only in the Mississippi Valley, but in America. A short time after this Journal had made its appearance, a Boston weekly devoted to medical science ceased publication, and for many years the St. Louis paper stood alone in the vast region west of the Alleghany Mountains as the sole exponent of medical science. From the outset it was conducted with signal ability, and as an ally in the progress of civilization in the Mississippi region its services cannot be measured.

The connection between the University and the Medical College was not destined to be permanent. When the "Know Nothing" excitement arose and began to spread over the land, in 1854 and 1855, it was decided by a majority of the medical faculty that it was expedient for the medical department, under the circumstances, to be separated from the University, and henceforth conducted under a distinct charter. By mutual consent, its connection with St. Louis University closed in 1855.

The school was incorporated under the name of the St. Louis Medical College[30] and continued as an independent school until 1891, when an offer of alliance with Washington University was accepted, and the school became the Medical Department of Washington University. In 1899 the Missouri Medical College was included, the united colleges continuing as the Medical Department of Washington University.

In 1901 the Marion-Sims College of Medicine was consolidated with the Beaumont Hospital Medical College, and in 1903 this Marion-Sims-Beaumont College of Medicine became the Medical Department of the St. Louis University.

In 1836 Kemper College[31] was incorporated with a uni-

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[30] Baumgarten, Gustav. The St. Louis Medical College. 1892.
Grindon, Jos. History of the St. Louis Medical College. 1898.
Goodwin, E. J. A history of medicine in Missouri. 131-133. 1905.

[31] White, Greenough. An apostle of the western Church. Memoir of the right reverend Jackson Kemper. 1900.

versity charter under the auspices of the Protestant Episcopal Church. This institution was located about four miles southwest of St. Louis, on a tract of land of 125 acres, adjacent to the old county farm of St. Louis County, and near the site of the present Insane Asylum. The college opened in October, 1838. In 1840 Dr. Joseph Nash McDowell organized a medical department, the first course of lectures being given in 1840-41 in a building erected on a high bank of Chouteau's Pond, at the corner of Ninth and Cerre streets, where some of the buildings of the Wainwright Brewery now stand.

Although Kemper College never attained the position among western colleges which its promoters had hoped it would, it was, nevertheless, a popular academic school for some years, but in 1845 was discontinued on account of lack of financial aid. The County Court of St. Louis County purchased the college buildings and used them as an asylum for the poor, known as the Poor House. When Kemper College failed, its medical department became the Medical Department of the State University, and was so conducted until the general reorganization of the State University, when a separate charter was procured under which the college was independently conducted as the Medical Department of the Missouri Institute of Science, more commonly known, however, as the Missouri Medical College,[32] or McDowell's College. The college was located on the corner of Eighth and Gratiot streets. At the beginning of the Civil War it was confiscated by the United States government and became a famous military prison, known as the Gratiot Street Prison. After the close of the war

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[32] Valentine, Mary T. (Mary Young Ridenbaugh.) The biography of Ephraim McDowell, M. D. 2nd ed. rev. 158-180. 1894.

Goodwin, E. J. A history of medicine in Missouri. 129-131. 1905.

Outten, W. B. Dr. Joseph Nash McDowell. Glimpses of early St. Louis medical history. Med. Fortnightly. 33-34: 143-146. 1908.

Barbee, A. B. History of the Missouri Medical College from 1840 to 1861. Jour. Mo. Med. Assoc. July, 1914.

the faculty was reorganized and lectures were resumed in the same building. After a career of fifty-nine years the Missouri Medical College in 1899, in conjunction with the St. Louis Medical College, became the Medical Department of Washington University.

In May, 1845, the faculty of the Medical Department of Kemper College started a journal called the "Missouri Medical and Surgical Journal," but in September, 1848, it was merged with the "St. Louis Medical and Surgical Journal."

Edward Wyman, who established an English and Classical High School in St. Louis in 1843, set about to form a museum of natural history under the direction of Mr. J. P. Bates. In his "Thoughts About St. Louis" Hogan says:

"For several years past Mr. Wyman has been collecting specimens of 'Natural History,' and has had engaged in their preparation and arrangement a gentleman of unquestionable skill, of which his work is a most conclusive demonstration. Mr. Bates, the naturalist employed in this department, works steadily, quietly, yet with all the enthusiasm of a true devotee to the science of his choice, in the tasteful preparation and arrangement of this beautiful cabinet. No pains, or expense, or labor is spared, either in the collection or preparation of these specimens. There are specimens from almost all lands, while river, lake and ocean furnish a few. Mr. Bates has just returned from Europe whither he went to collect rare specimens, and returned laden with spoils. The collections, especially in the department of ornithology, are as fine as I have ever seen anywhere—probably finer than can be found in this country, not so much for the great number of specimens—for it is very select—but for their beauty, their rarity, and the tasteful manner of their preparation and display. Indeed, there are many specimens, both in this and other branches, which I have not seen in other cabinets and museums in the United States, and I doubt if they can be found in private or public cabinets in this country. This whole Museum now embraces some two thousand and five hundred specimens, and there are many very choice ones brought by Mr. Bates from Europe in his last visit, not yet put up."

This museum, which was on the third floor of Wyman's Hall, on Market street, opposite the Court House, was purchased in 1851 by Dr. Albert C. Koch and conducted for some years as the St. Louis Museum or Koch's Museum.

In 1853 Wayman Crow secured from the Legislature of Missouri a charter for an educational institution in St. Louis to be called the Eliot Seminary. The gentlemen named in this charter met and organized, and chose William G. Eliot, President, in 1854. In deference to the wishes of President Eliot the name of the institution was changed to the Washington Institute, and in 1857, when the charter was amended, to Washington University.[33] The university was formally inaugurated in 1857—in President Eliot's words, "An institution for the public benefit."

Washington University has always been in close touch with the Academy of Science of St. Louis. From its faculty have come some of the most active workers and officers of the Academy. To the Transactions they have contributed many and important papers. At a time when the Academy had no other home the doors of the university were opened to it for its meetings and the housing of its library and collections.

In 1857 Henry Shaw,[34] a wealthy retired merchant of St. Louis, who had a large garden connected with his country home, commissioned Dr. Engelmann, then in Europe, to examine botanical gardens and make such suggestions as he might deem of value in establishing a botanical garden. The Missouri Botanical Garden[35] is the offspring of Dr. Engelmann's researches in that line.

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[33] Twenty-fifth anniversary. 1882.

Chaplin, W. S. Higher education in St. Louis and Washington University. 1893.

Snow, M. S. Higher education in Missouri. 129-163. 1898.

Eliot, C. C. William Greenleaf Eliot, minister, educator, philanthropist. 1904.

Washington University 1857-1907. 1907.

[34] Dimmock, Thos. Report Mo. Bot. Garden. 1: 7-25. 1890.

[35] Trelease, Wm. The Missouri Botanical Garden. Rept. Mo. Bot. Gard. 1. 1890.

Trelease, Wm. The Missouri Botanical Garden. Pop. Sci. Month. 62: 193-221. 1903.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 246-250.

In 1859 Mr. Shaw secured the passage of an act of the Legislature of Missouri which empowered him to deed or will to trustees such of his property as he wished to set aside for the following purposes, namely: "to maintain and establish a botanic garden for the cultivation and propagation of plants, flowers, fruit and forest trees, and for the dissemination of the knowledge thereof among men, by having a collection thereof easily accessible; by the establishment of a museum and library in connection therewith, as also by establishment of public lectures and instruction upon botany and its allied sciences, when it shall be deemed advisable in furtherance of the general objects of said trust; and for the purpose of maintaining a perpetual fund for the support and maintenance of said garden, its care and increase, and the museum, library and instruction connected therewith."

After Mr. Shaw's death the Missouri Botanical Garden was organized in accordance with the terms of his will. At the Garden will be found one of the best botanical libraries in America, and among a vast herbarium of plants representative of every corner of the earth will be seen the Engelmann collection, containing many rare specimens of important types of plants collected by some of the early western explorers.

In 1885 Mr. Shaw proposed to the directors of Washington University to endow in that institution a school of botany with the understanding that by testamentary provision the best use of his garden for scientific study and investigation should be insured to its professors and students. The offer was accepted and the Henry Shaw School of Botany formally inaugurated.

Among those who came to America in 1848 because of dissatisfaction with the established government of Baden, Germany, was Dr. Adam Hammer,[36] who arrived

[36] Dr. Adam Hammer. St. Louis Med. Surg. Jour. 35: 314-316. 1878. Goodwin, E. J. Humboldt Medical College. A history of medicine in Missouri. 136. 1905.

in St. Louis with his faithful friend, Hecker, on October 28, 1848. Dr. Hammer soon became convinced of the need of reform in American medical education, and, in 1855, obtained from the Legislature of Missouri a charter for an institution to carry out his ideas. The St. Louis College of Medical and Natural Sciences was founded for the specific purpose of placing American medical education upon a plane similar to that of the best foreign universities. It was the first medical school in the United States to require high preliminary qualifications for matriculation, a graded course of instruction, and four courses of lectures. In those days the time allotted to the study of medicine was two courses of four months each, the same lectures being given in the second course that had been delivered in the first. All branches of medical science were taught in four months, the student getting the alpha and omega of the science in one term. Dr. Hammer insisted on four courses of lectures in a graded course of instruction. This institution was compelled to close its doors in 1856.

In the fall of 1859 Dr. Hammer opened the "Humboldt Institut, oder Deutsche Naturwissenschaftlich-Medicinische Schule in St. Louis." This college was unique in the annals of American medicine in that instruction was given in the German language. During the early part of the Civil War the college was closed, but was reopened later on and lectures were given until 1866, when the name was changed to the Humboldt Medical College, which ceased to exist in 1869 because of a split in the faculty.

At the inauguration of the Henry Shaw School of Botany of Washington University in 1885, Chancellor Eliot in the course of his address said:

Outten, W. B. Dr. Adam Hammer. Glimpses of early St. Louis medical history. Med. Fortnightly 33-34. 171-173. 1908.

Ball, J. M. Dr. Adam Hammer, surgeon and apostle of higher medical education. Jour. Mo. State Med. Assoc. 6: 3. 1909.

"More than forty years ago, five or six young men, of whom I was one, met together, on Main street, near Chestnut, in the office of the Honorable Judge, Mary P. Leduc. The object was to found an Academy of Science, but not one of our number really knew enough of science to found a primary school, except Dr. George Engelmann, who was an enthusiastic student, especially in botanical research, and who inspired us all with something of his zeal. We organized a society and proceeded to purchase five or six acres of ground, far out of the city, I think near Eighth street and Chouteau avenue. There Dr. Engelmann began a botanical garden and aboretum on a small scale. It was kept up, after a fashion, for some years, but the society faded out and the land was sold, and apparently there was an end of the academy. But under the law of the survival of the fittest, Dr. Engelmann 'survived' and became an academy of science in himself."

This was the Western Academy of Natural Sciences.[37] The foundation for this first edifice of science in the Mississippi Valley and probably the first west of the Alleghany Mountains was laid in 1837, when a charter was granted to H. King, George Engelmann, B. B. Brown, P. A. Pulte, William Weber, Theodore Engelmann and G. Schuetze, as incorporators. The main promoters of this new society were Dr. Engelmann and Dr. Wislizenus, both destined to play important rôles in the future Academy of Science.

Through the efforts of these men the lamp of science was kept burning for some years, at a time when St. Louis was nothing more than a small frontier town. An address, together with the Act of Incorporation, Constitution and By-Laws, were respectfully submitted to the "friends of knowledge," soliciting funds, new members, and contributions to the proposed museum and library.

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[37] Act of incorporation, constitution and by-laws of the Western Academy of Natural Sciences at St. Louis. 1837.

The address stated that St. Louis was most fortunately situated for work in natural science, being on the edge of that "immense tract of country that lies between the western borders of civilization and the Pacific ocean," upon which "the attention of the scientific world is every day becoming more strongly fixed," because of its geological peculiarities, its immense mineral resources and its abundant fauna and flora.

A museum had been started, an effort made to establish a botanical garden, and a library of about one hundred volumes gathered, when, through lack of support, the Western Academy of Natural Sciences ceased to exist. Just how many years the Academy was active is not known. On April 17, 1843, however, the society elected to honorary membership John James Audubon. The diploma was signed by George Engelmann, President; B. B. Brown, Vice-President; Wm. R. Singleton, Corresponding Secretary; and L. M. Sell, Recording Secretary.

For a score or more years informal metings of the local scientists were no doubt held and the slumbering Academy discussed. Finally the opportune moment for relighting the lamp of science seems to have arrived, when, according to previous agreement, Drs. Engelmann, Prout, Wislizenus, Pope, Pallen, Tingley, Stevens, McPheeters, and Shumard, and Messrs. Charles P. Chouteau and James B. Eads assembled on the eighth of February, 1856, to form in St. Louis a society for the cultivation of various branches of science. Dr. Engelmann was called to the chair, and Dr. Shumard appointed Secretary. Dr. Pallen stated that the acknowledged want of an institution in the west for the cultivation of various branches of science had caused a desire in the minds of those present to found one in this city. Its object should be especially the investigation of subjects pertaining to the various branches of science, the accumulation of a scientific library, and the formation of a museum, which should contain collections in the various departments

embraced in the term, Science, and also objects illustrating the manners and customs of the aborigines of North America. Dr. Engelmann remarked that to establish firmly such a society it would be necessary to collect a certain amount of money. It was also deemed advisable to secure for the society certain valuable collections of fossil remains and other natural objects now in the city. Drs. Tingley and Shumard and Mr. Chouteau were asked to prepare a circular to be addressed to such persons as might be favorable to the objects in view.

At the last preliminary meeting a Constitution and By-Laws were adopted, and an election held, which resulted in the choice of the following gentlemen as officers:

President	George Englemann.
First Vice President	Hiram A. Prout.
Second Vice President	Nathaniel Holmes.
Secretaries	Benjamin F. Shumard, Wm. H. Tingley.
Treasurer	James B. Eads.
Curators	Moses M. Pallen, Adolph Wislizenus, Charles W. Stevens, Benjamin F. Shumard.
Board of Council	George Engelmann, H. A. Prout, Nathaniel Holmes, B. F. Shumard, Chas. A. Pope, Wm. H. Tingley, Chas. P. Chouteau.

After several preliminary meetings respecting the organization of the Society, a meeting was held on the tenth of March, 1856, in the Hall of the Board of Public Schools, at which were present the following fifteen founders of the present Academy of Science:[38] George Engelmann, Hiram A. Prout, Moses M. Pallen,[39] Benja-

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[38] Starr, Frederick. The Academy of Science of St. Louis. Pop. Sci. Month. Mar., 1898.

Trelease, Wm. The Academy of Science of St. Louis. A biography. Pop. Sci. Month. Dec., 1903.

Celebration of the fiftieth anniversary of the first meeting. Trans. Acad. Sci. St. Louis. 16: i-xcix. 1906.

[39] Moses M. Pallen. Trans. Acad. Sci. St. Louis. 3: ccxxii. 1876.

Moses M. Pallen. Trans. Amer. Med. Assoc. 28: 620. 1877.

Moses M. Pallen. St. Louis Cour. Med. 30: 383. 1904.

min F. Shumard, Charles A. Pope, William H. Tingley, James B. Eads, William M. McPheeters, Simon Pollak,[40] Charles W. Stevens,[41] Adolph Wislizenus, Nathaniel Holmes,[42] M. L. Linton, J. H. Watters,[43] and Charles P. Chouteau.

Dr. Engelmann[44] came to America in 1832 and settled in St. Louis in 1834. For fifty years his explorations and investigations made the city respected as the home

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Outten, W. B. Dr. M. M. Pallen. Glimpses of early St. Louis medical history. Med. Fortnightly. 33-34. 146-148. 1908.

[40] Simon Pollak. St. Louis Med. Rev. 48: 397-403. 1903.

Alt, Adolf. Simon Pollak. Amer. Jour. Ophth. 20: 350. 1903.

Lutz, F. J. The autobiography and reminiscences of S. Pollak. 1904.

Goodwin, E. J. A history of medicine in Missouri. 39-41. 1905.

[41] Charles W. Stevens. St. Louis Med. Surg. Jour. 58: 196. 1890.

Goodwin, E. J. A history of medicine in Missouri. 39. 1905.

Outten, W. B. Dr. Chas. W. Stevens. Glimpses of early St. Louis medical history. Med. Fortnightly 33-34: 310-313. 1908.

[42] Nathaniel Holmes. Trans. Acad. Sci. St. Louis. 11: xxvii-xxviii. 1901.

[43] John Henry Watters. St. Louis Cour. Med. 30: 382. 1904.

[44] Körner, Gustav. Das deutsche Element in den Vereinigten Staaten von Nordamerika 1818-1848. 327-331. 1880.

Gray, Asa. Memorial of George Engelmann. Amer. Jour. Sci. III. 28: 61-67. 1884.

Gray, Asa. George Engelmann. Proc. Amer. Acad. Arts and Sci. 19: 516-522. 1884.

Gray, M. L. George Engelmann. Trans. Acad. Sci. St. Louis. 4: xc-xcv. 1884.

Sargent, C. S. George Englemann. Science. 3: 405-408. 1884.

Sander, Enno. George Engelmann. Biography. Trans. Acad. Sci. St. Louis. 4: 1-18. 1886.

Sketch of George Engelmann, M. D. Pop. Sci. Month. 29: 260-265. 1886.

Trelease, Wm. and Gray, Asa. The botanical works of the late George Engelmann collected for Henry Shaw, Esq. Edited by. 1887.

Boisliniere, L. C. Biographical notice of George Engelmann. St. Louis Med. Surg. Jour. 65: 364-368. 1893.

White, C. A. Memoir of George Engelmann. 1809-1884. Biog. Mem. Nat. Acad. Sci. 4: 1-21. 1902.

George Engelmann. 1809-1909. Trans. Acad. Sci. St. Louis. 18: xlvii-l. 1909.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 125-129.

White, C. A. George Engelmann. A history of the first half-century of the National Academy of Sciences 1863-1913. 129-132. 1913.

of science among men of learning at home and abroad. His early stay in America he spent in study in and around St. Louis, carrying his investigations to southern Illinois, southern Missouri, and into Arkansas. The reports which Dr. Engelmann made upon the resources of the Mississippi Valley in the vicinity of St. Louis were the principal features of a periodical called "Das Westland," published in Heidelberg in the interests of German emigration to the Mississippi Valley.

Dr. Engelmann was not only one of the leading medical practitioners, but one of the foremost botanists of his day. During many years of an active, useful life he found sufficient time, in the leisure hours of his practice, to devote to a series of most valuable scientific investigations. In addition to his professional and botanical labors, he was a zealous meteorologist. On establishing his home in St. Louis, he began a series of thermometrical and barometrical observations, which he continued regularly and systematically for nearly fifty years—anticipating by a full third of a century the local observations of the United States Weather Bureau. After his death the Academy published his observations covering a period of forty-seven years.

In 1859 Dr. Engelmann published a paper concerning the elevation of St. Louis above sea level. This was an important paper for the reason that St. Louis was then the point upon which were based the computations for determining the altitudes of such places in the Far West as were visited by the early exploring expeditions of Nicollet, Frémont, Emory, and others. Dr. Engelmann, after a series of barometric observations in 1853, determined a directrix of 404.9 feet for the city of St. Louis—a figure which differed by only 7.8 feet from the 412.7 feet mark as determined later on by exact leveling of government departments, and by only 2.2 feet from the original 410.5 of Nicollet, which was made in 1841 by barometric determinations based upon data furnished in part by Dr. Engelmann himself.

On coming to the Mississippi Valley, Dr. Engelmann found himself surrounded by plants, most of which were unknown to him. He studied them systematically in their relations to each other, devoting himself to a particular genus or group of plants until he had thoroughly mastered it. Among his many investigations of plants was that of the Cactus family, upon which his work was most extensive and important. His treatise on this family is still quoted as the highest authority. This stupendous task was begun in his sketch of the botany of the expedition of Dr. Wislizenus to northern Mexico and was concluded with two illustrated memoirs, one contributed to the fourth volume of the Pacific Railroad Expedition Reports, and the other to Emory's Report on the Mexican Boundary Survey. His splendid work on the two peculiarly American groups of plants, the Yucca and Agave, was published in the third volume of the Transactions of the Academy of Science. His various papers on the American oaks and conifers, published in the Transactions of the Academy and elsewhere, are of the highest interest to science. Nearly all that we know scientifically of our species and forms of grapes is directly due to Dr. Englemann's investigations. Much of his work on the grape vines of Missouri was published by the Academy of Science.

In the year following his death the principal professorship in the Henry Shaw School of Botany, which was then established, was named after him. His friend and co-worker, Dr. C. C. Parry, named for him a peak in the Rocky Mountains and also the picturesque cañon through which now passes the cog wheel railroad from Manitou to the summit of Pike's Peak. The name Engelmann has become unalterably associated with the Buffalo grass of the plains, with the noblest Conifers of the Rocky Mountains, and with the most stately Cactus in the world, verifying the prediction of his biographer that "the Western plains will still be bright with the yellow rays of *Engelmannia,* and that splendid Spruce, the fairest of them all,

which bears the name of Engelmann, will still, it is to be hoped, cover with noble forests the highest slopes of the Rocky Mountains, recalling to men, as long as the study of trees occupies their thoughts, the memory of a pure, upright, and laborious life."

Associated with Dr. Engelmann in the earlier years of his career in St. Louis was Dr. Adolphus Wislizenus, whose name will ever be honorably associated with the history of science in St. Louis. Although Dr. Wislizenus had settled in St. Louis to practice medicine, scientific exploration lured him on two extensive expeditions—one in 1839 to the Rocky Mountains and the other in 1845 to northern Mexico. The results of his Mexican tour will be regarded as his most valuable contribution to science, having been publicly acknowledged by Humboldt as of value to him in his studies of that region.

Among some of the many other distinguished members of the Academy of Science, whose memories we honor and cherish and to whom we are indebted for liberal contributions to knowledge—often acquired under the most trying circumstances—are Hiram A. Prout, to whom is justly due the credit of having first called attention to the existence of the gigantic extinct remains in the Bad Lands of Nebraska by his excellent memoir on Palaeotheroid and other bones, and for whom the *Titanotherium Proutii* will stand as a lasting monument in the world of science; James B. Eads,[45] who devised and furnished our Government with its first and most useful armored steamboats, who constructed the bridge spanning the Mississippi at St. Louis which bears his name, and who by means of jetties at the mouth of the Mississippi opened

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[45] James B. Eads. Trans. Acad. Sci. St. Louis. 5: xiii-xv. 1887.
James B. Eads. Sci. Amer. Supp. Apr. 9, May 7, 1887.
Corttell, E. L. James B. Eads. Jour. Assoc. Eng. Soc. 9: 456-461. 1890.
Sellers, Wm. Memoir of James Buchanan Eads. 1820-1887. Biog. Mem. Nat. Acad. Sci. 3: 59-80. 1895.
How, Louis. James B. Eads. 1900.

an unobstructed pathway or channel from the Mississippi to the Gulf of Mexico; Charles V. Riley,[46] the investigator of the ravages and life history of the Rocky Mountain Locust and the organizer and first head of the United States Bureau of Entomology, the man who saved the grape industry of Europe from the ravages of the American Phylloxera by grafting the susceptible European varieties upon roots of the more resistant American species; Benjamin F. Shumard,[47] of the Missouri State Geological Survey, and later State Geologist of Texas; George Clinton Swallow, who conducted the geological survey of this state from 1853 to 1860 and made known the vast coal beds of Missouri; Theodore C. Hilgard,[48] whose work on phyllotaxis and kindred subjects is well known, and Abram Litton,[49] the first thoroughly trained chemist west of the Mississippi.

The act of incorporation declares the object of the Academy to be the advancement of science and the estab-

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[46] Nipher, F. E. Charles V. Riley. Trans. Acad. Sci. St. Louis. 7: xlvi-xlvii. 1895.

Packard, A. S. Charles Valentine Riley. Science. II. 2: 745-751. 1895.

Goode, G. B. A memorial appreciation of Charles Valentine Riley. Science. II. 3: 217-225. 1896.

Howard, L. O. Charles Valentine Riley. Proc. Soc. Pro. Agric. Sci. 17: 108-112. 1896.

Howard, L. O. Charles Valentine Riley. Bull. Phil. Soc. Washington. 13: 412-416. 1900.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 251-252.

[47] Benjamin F. Shumard. Trans. Acad. Sci. St. Louis. 3: xvii. 1869.

Benjamin F. Shumard. Amer. Jour. Sci. II. 48: 294-296. 1869.

Benjamin F. Shumard. St. Louis Med. Surg. Jour. II. 6: 286. 1869.

Yandell, L. P. A biographical sketch of Benjamin Franklin Shumard. Western Jour. Med. 4: 738-749. 1869.

[48] Theo. C. Hilgard. Trans. Acad. Sci. St. Louis. 3: clxxvi. 1875.

Spaulding, Perley. A biographical history of botany at St. Louis, Missouri. Pop. Sci. Month. 1909: 130-133.

[49] Broadhead, G. C. Abram Litton, M. D. Acad. Sci. St. Louis. 12: xxiv-xxvii. 1902.

Abram Litton. St. Louis Cour. Med. 30: 312-313. 1904.

lishment in St. Louis of a museum and library for the illustration and study of its various branches.

At the second meeting of the Academy, April 21, 1856, the generous offer of Dr. Charles A. Pope for the free use of the Cabinet Hall and other rooms in the Dispensary Building of the St. Louis Medical College, was thankfully accepted. In Pope's College were established the first museum and library of the Academy.

At a special meeting called by the President, August 4, 1856, the library, belonging to the Western Academy of Natural Sciences, consisting of 120 volumes, the mineralogical and geological collection, cases and apparatus, were donated to the Academy.

During the first year of its existence the progress of the Museum had been so encouraging that standing committees were appointed in the following subjects:—Ethnology, Comparative Anatomy, Mammalogy, Ornithology, Herpetology and Ichthyology, Chemical Geology and Malacology, Entomology, Botany, Palaeontology and Geology, Mineralogy, Chemistry, Physics, Embryology and Monstrosities. At the end of the second year Astronomy and Meteorology were added.

Prominent among the donors appears, again and again, the name of Mr. Charles P. Chouteau,[50] who was ever mindful of the Academy's needs when on his expeditions into the Far West in the interests of the fur trade. At one of the meetings he requested the Academy "to name some naturalist to accompany him on his expedition to the Upper Missouri free of expense to the society." At another time we find recorded in the minutes that "numerous mounted and preserved specimens of mammals, birds, reptiles and fishes, collected on the Upper Missouri river by the taxidermist sent by the Academy to accompany Mr. Charles P. Chouteau, on the annual trip of the American Fur Company's boats, were received

[50] In memoriam Charles Pierre Chouteau. Trans. Acad. Sci. St. Louis. 11: xxi-xxii. 1901.

and deposited in the Museum." Of the many and priceless gifts of Mr. Chouteau only a section of the Fort Pierre meteorite now remains, the balance having been destroyed in the fire of 1869.

Even the gloomy days of the Civil War added to the Academy's museum. The Western Sanitary Commission deposited with the Academy what remained of the natural history collection of McDowell College, which had been confiscated and turned into a federal prison.

At the close of the war the Academy regained some of its accustomed activity, and, in the Fall of 1868, a committee was appointed to secure rooms in the Polytechnic Building, as the museum and library had far outgrown the quarters in Pope's College. While negotiations were still pending, fire broke out in May, 1869, destroying almost the entire museum. Fortunately the library was saved. The loss of the Academy museum was irreparable and no efforts were made to re-establish it until a few years ago.

The palaeontological collections were perhaps the most valuable part of the museum. They contained a large number of teeth and bones of *Mastodon giganteus* and *Elephas primigenius,* in good preservation, from Missouri and other western states; a full skeleton of the great cave bear from Europe; a fine example of the head of *Bos bombifrons,* an extinct fossil ox exhumed from Chouteau's Pond. This fossil is so rare that only two specimens had been discovered previously. The Academy's specimen withstood the fire and is in its present museum. Through the liberality of Mr. Charles P. Chouteau the Academy had obtained an extensive and beautiful collection of fossils, collected by F. V. Hayden in the Bad Lands of Nebraska, which had later been increased by the purchase of the one-fourth interest owned by Colonel A. J. Vaughan. This gave to the Academy an equal share with the Academy of Natural Sciences of Philadelphia in the splendid collection made by the United States Geological Survey of the Territories from

the Bad Lands and other portions of the Upper Missouri country. In this collection were fourteen specimens of extinct fossil turtles, the remains of the gigantic Titanotherium, two species of extinct rhinoceros, a hyena, and two species of Oreodon. In the geological department were also rocks, mineral and ores collected by Dr. Wislizenus during his exploration of northern Mexico; cretaceous and tertiary fossils obtained by Dr. Koch while Zeuglodon hunting in Mississippi and Arkansas; fossils from the carboniferous and cretaceous formations of Texas and New Mexico; a series of rocks and fossils collected by the expedition of Lieutenant Bryan on his survey of a wagon route from Kansas to Utah in 1860-61; and type specimens of fossils from the Upper Missouri, collected by Lieutenant G. K. Warren.

In the mineralogical department were over twelve hundred specimens of minerals from various parts of the United States and a collection of meteorites, among them the Fort Pierre meteorite, found about twenty miles from Fort Pierre and brought to St. Louis by the American Fur Company in 1857. When found it weighed thirty-five pounds. A section of this meteorite is still in the Academy museum.

In the museum of the Academy were also housed choice suites of reptiles, skulls and skins of mammals from the Platte River country and other portions of the Rocky Mountains; bird skins collected by Captain John Pope in California, Texas and New Mexico; mounted specimens of grizzly bear, Rocky Mountain sheep and goats, heads of buffalo, specimens of several species of deer and various smaller animals from the Rocky Mountain region; several hundred birds donated by the Academy of Natural Sciences of Philadelphia and the Smithsonian Institution in exchange for other specimens; unusually fine specimens of skeletons and crania of over one hundred species of mammals, birds and reptiles, and the fine collection of Dr. Pope of choice mounted skeletons of mammals purchased in Europe; several hundred plants

collected around St. Louis and in Louisiana in 1828-29 by the Right Reverend Rosati, Bishop of St. Louis; a valuable collection of marine and fresh water shells; insects, especially those injurious to vegetation; star fishes and sea urchins; and an extensive series of lichens and mosses, chiefly from western states and territories, and papier maché models of fungi, colored true to nature, presented by Dr. T. C. Hilgard.

Here were to be found distorted crania from mounds near Little Rock, Arkansas, also stone axes, spear and arrow heads, quoits, shells and beads and other aboriginal implements and ornaments from western states, Indian costumes, war implements, cooking utensils and ornaments of the Upper Missouri Indians; a beautiful series of porcelain ornaments in bas-relief, representing figures of men and animals, and used as decorations in the great Porcelain Tower of China; also highly polished bricks employed in its construction.

During the years that the Academy was tenanted in the Public School Library Building, the Washington University, and the Missouri Historical Society, what was left of the museum and such small accessions as were acquired from time to time were stored in basements, and, consequently, of no use to the members or to the public.

However, during the bright days of the Archaeological Section in 1876 and 1877, excavations were made by the Academy in the mounds of southeastern Missouri, in northern Arkansas and in Illinois, the partial results of which were published in a quarto memoir. The pottery and the crania obtained then are among the treasures of the present museum.

In 1900 the Academy purchased the Yandell Collection of palaeontological specimens, containing many of Yandell's own type specimens and of those described by Shumard, whose collection is owned by Washington University. This collection is especially rich in Crinoids of the Devonian Age and many rare types contained in it are described in the first volume of the Transactions.

The purchase of this collection by the Academy placed in St. Louis two of the best fossil collections in existence to which students may refer in their scientific researches for typical specimens characteristic of this section of the country.

In 1901, through the efforts of Mrs. Wm. L. Bouton, the Academy acquired a collection of six hundred and thirty-five butterflies, mostly tropical.

When the Academy moved into its own home in 1903 new efforts were made to again establish a museum of natural history worthy of the name. Besides the Yandell and butterfly collections, the Academy has on exhibition a fine collection of mound builder pottery and some forty human skulls from the mounds near New Madrid, Missouri; a collection of song birds and birds of prey, deposited with the Academy by the Missouri Botanical Garden; many minerals from all parts of the United States; a small collection of fossil leaves; a collection of twenty-five meteorites, among them a section of the Fort Pierre meteorite; some fine fossiliferous slabs, mostly from St. Louis limestone and of great value; some of the fossils of the Hayden Survey, containing the type of *Titanotherium Proutii;* and a good specimen of *Bos cavifrons* (a species of fossil ox).

Hand in hand with the formation of a museum went the acquisition of a library. In the first year of its existence the Academy received the library, consisting of one hundred twenty volumes, of the Western Academy of Natural Sciences. With this as a nucleus, efforts were made to secure the publications of other scientific societies. Letters were sent to kindred societies and the exchange value of publications soon became evident. A committee was appointed to consider the question of undertaking some form of publication. After considerable thought and discussion the publication of "Transactions" was decided upon, and the first number was issued early in 1857. It contained in addition to the charter, constitution and by-laws, and journal of proceedings,

the following articles:—On some new species of fossils from the Cretaceous formation of Nebraska Territory, by John Evans and B. F. Shumard; Description of a new species of Productus from the Carboniferous limestone of St. Louis, by Hiram A. Prout; Observations on glycerin, by James Schiel; Phyllotaxis—its numeric and divergential law explicable under a simple organological idea, by T. C. Hilgard; Mastodon remains, in the State of Missouri, together with evidences of the existence of Man contemporaneously with the Mastodon, by Albert C. Koch; Notice of a burnt brick from the ruins of Nineveh, by G. Seyffarth; Indian stone graves in Illinois, by A. Wislizenus; Description of new fossil Crinoidea from the Palaeozoic rocks of the western and southern portions of the United States, by B. F. Shumard; Belcher and Brothers Artesian well, by A. Litton; Meteorological observations for 1856 made in St. Louis by Drs. Engelmann and Wislizenus.

Since its organization the Academy has issued twenty-two volumes of Transactions, and on two occasions special works. One, entitled "Contributions to the Archaeology of Missouri" by the Archaeological Section, is devoted to the description and illustration of the pottery obtained by a party from the Academy which investigated the mounds in the neighborhood of New Madrid. In 1889 the Academy sent observers into the field to study the total eclipse of that year. Their report, entitled "Total Eclipse of the Sun, January, 1889. A report of Observations made by the Washington University Eclipse Party at Norman, California," was published by the Academy in a quarto of 39 pages and 6 plates.

While no serious efforts were made after the fire of 1869 during some thirty years to re-establish the museum, the energies of the Academy during that time were devoted to the formation of a library by the liberal exchange of publications. The first society to recognize the new organization was the Academy of Natural Sciences of Philadelphia, which donated to the library a set

of its "Proceedings" and the second series of its "Journal." By exchange the Academy has received many valuable series issued by kindred societies all over the world, most of which have been received without interruption and prove indispensible to investigators who desire to go into the earlier literature of their subjects. Today publications are exchanged with 306 foreign and 114 home societies.

The growth of the Academy in recent years has been essentially along the lines defined by its founders. Its library has been steadily increased through its affiliations with other scientific bodies in this and foreign countries; its collections are housed and its meetings held in its own building; and the Transactions have been published in unbroken series and kept up to a high and worthy standard.

As the present must ever be accumulating knowledge for the future, the influence of the Academy of Science will grow greater and greater as the years go by, bringing within its folds all those interested in the development of science, fostering and strengthening the scientific spirit, and passing on from generation to generation the achievements of science, as expressed in its motto, "for human knowledge and power."

Issued December 29, 1914.

THE AGAVEAE OF GUATEMALA.*

WILLIAM TRELEASE.

The records of *Agave* and *Furcraea* as Guatemalan plants are neither extensive nor convincing. Hemsley in his summary of Central American plants attributes *Agave Sartorii* and *A. Seemanniana*[1] to Guatemala, as he does *Furcraea longaeva* and *F. Selloa.*[2]

Agave Sartorii is a species characteristic of the forests of the coastwise flanks of Mt. Orizaba, Mexico, where, as Roezl[3] notes for *A. attenuata,* and as I have myself observed about Cuernavaca, in western Mexico, for *A. Mescal,* it is sometimes epiphytic. The name given it is commemorative of Sartorius, a German settler, whose hacienda El Mirador at Huatusco, in the Mexican state of Vera Cruz, is the type locality of numerous species collected either by him or by the botanical guests who even yet make it their headquarters. The only reason for supposing that *A. Sartorii* occurs in Guatemala lies in the statement of its describer[4] that it was sent by Rohrbach to Berlin from Orizaba, and also by Sartorius to Darmstadt from the same place *or from Guatemala.*[5] *Agave Seemanniana* is said

*Presented before The Academy of Science of St. Louis, June 7, 1915.

1 Biologia Centrali-Americana. 3: 349.

2 *l. c.* 3: 353.

3 Roezl, Belgique Horticole. 1882: 98.

4 Koch, Wochenschr. Verein Beförd. Gartenbau. 3: 37. 1860.

5 "Andernseits wurde sie durch den Reisenden Sartorius eben daher oder aus Guatemala an den Garten-director Noack in Darmstadt gesendet."

by its describer[6] to have been discovered by Dr. Berthold Seemann in the colony of New Segovia in the republic of Guatemala and introduced by him into English gardens by means of seeds. I do not know of a Guatemalan town called Segovia, however, and the seedsman who first advertised the plant in the autumn of 1867 as *A. Seemanni*,[7] says that it was collected by Seemann in stony places in the department of Matagalpa, Nicaragua—which, indeed, is adjacent to Segovia. There seems to be no evidence therefore that *A. Sartorii* is Guatemalan; but what is taken for *A. Seemanniana* does occur in eastern Guatemala, some 300 miles northwest of the Nicaraguan region from which it really seems to have been described.

Herbaria, so far as I have seen them—and I have examined the principal collections of the world, give as little evidence as do publications that the genus *Agave* occurs in Guatemala, except that of late years several amiable correspondents have sent me specimens that are preserved at the Missouri Botanical Garden.

My own connection with the matter dates from the early part of 1901, when I observed several rosette-forming agaves along the trail from El Rancho, on the Motagua River—where the railroad from Puerto Barrios then stopped—to the capital. At that time I was making a hurried survey of the distribution of *Yucca guatemalensis* (or *elephantipes*), and collected no agaves, and it was not until the present spring that I found opportunity to study these plants through a short leave of absence kindly granted by the President and Trustees of the University of Illinois, supplemented by an honorary commission from the Secretary of Agriculture of the United States. The following pages summarize what I have been able to ascertain in the field and from a study of the specimens that were sent me while I was

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[6] v. Jacobi, Abhandl. Schles. Gesellsch. 1869: 154.
[7] Bull, List. 22: 3.

at the Missouri Botanical Garden, for the use of which I am indebted to the present Director of the Garden.

From repeated observations on the Mexican species of this genus and the conspicuous localization of those of Baja California[8] and the West Indies,[9] I have been quite prepared to find that in Guatemala the agaves are distinctly different—not only in species but in characteristic groups—from those of Mexico, while differing even more markedly from those of the Antilles. Unfortunately the greater number of those here reported must be differentiated on vegetative characters only, so that it is quite within the range of possibility that some of them may be found divisible when added material comes to hand. I have shown in earlier studies[10] that the characters derivable from the arming of the leaves in this genus are remarkably constant, and the foliage indications are that all of the Guatemalan species are Euagaves.

My personal opportunities for study and collection in Guatemala have extended only to the central mountain region, in which a marked division of the year into a rainy and a dry season occurs, the contrast between which is so great that the majority of plants lose their foliage and pass into a dormant state, with well developed scaly buds, for the long dry season, just as our northern plants hibernate, though the Guatemalan temperature may be even higher than in the rainy season. So far as I know, none of the agaves occur spontaneously at less than about 2000 feet above sea level, though one cultivated species does well to within a few hundred feet of the sea on the Pacific slope. That the dry region about Salamá, which I have not been able to visit, may furnish other species is very probable, and almost half

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[8] Trelease, Rept. Mo. Bot. Gard. 22: 38-41. 1912.

[9] Trelease, Memoirs Natl. Acad. Sci. 11: 6-11, etc. 1913.

[10] Trans. Acad. Sci. St. Louis. 18: 31. 1909.—Proc. Amer. Philos. Soc. 49: 232-7. 1910.—Mem. Natl. Acad. Sci. 13: 12. 1913.

of the Republic, West of British Honduras, is unexplored; the prospect, nevertheless, is that the total number of agaves indigenous to Guatemala will scarcely be found to double the number now reported. For the convenience of those whose interest includes the parks or other public places of the capital or experimental plantations of fiber plants, I have included in the following treatment the very few cultivated agaves that I have seen in Guatemala.

The most striking geographic fact revealed by what are now known is undoubtedly that the spicate subgenus of *Agave,* Littaea, does not appear to reach into Central America any more than into the West Indies;—though as Littaeas occur in the southern Cordillera of Mexico there would be nothing surprising if some of them were to be found in the Guatemalan continuation of those mountains.

The *Furcraea* records for Guatemala are scarcely more convincing than the *Agave* records. *F. longaeva,* the most remarkable representative of its genus if not the most noteworthy lilioid plant, figures in one of the vignettes of Bateman's superb work on orchids,[11] and is said to have been seen by Skinner in the high mountains of that country. There is no improbability in this, since its type locality is the cordillera of Oaxaca in adjacent Mexico in which region it has been recollected recently.[12] At first sight, *F. Selloa* seems to be even more definitely fixed as Guatemalan, for its author, though describing it from a specimen cultivated in Europe, states that it was collected by von Warscewicz on the volcano of Quassaltenango, Guatemala.[13] Of recent years, that caulescent garden *Furcraea* that Mr. Baker took for *cubensis* has generally been accepted as *F. Selloa;* there is reason to believe that this comes from Co-

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[11] Bateman, Orchid. of Mex. & Guatemala. Vignette to *pl. 16.* 1843.
[12] Purpus, Möller's d. Gärtn.-Zeit. 26: 10. *f. 1-3.* 1911.
[13] Koch, Wochenschr. Verein Beförd. Gartenbau. 3: 22. 1860.

lombia; and Mr. Drummond, in his summary review of the genus,[14] expresses the opinion that its Guatemalan origin seems to require verification. Accepting this view, particularly as the descriptions of *F. Selloa* do not well fit the only species of the Quezaltenango region —which is very clearly distinct from what is commonly cultivated as *F. Selloa,* I should say that as yet none of the larger-toothed group Eufurcraea has been shown to be Guatemalan. Three such species actually occur in the Republic: one known only locally on the East slope; one extending from some 2500 feet altitude on the eastern slope through the district of Guatemala City at about 5000 feet to something like 2500 feet above sea-level on the western slope; and the third at rather higher altitudes in the mountains about Quezaltenango. The second and third of these are somewhat abundant, especially the second, and a good deal of fiber is prepared from them by crude means, though not on a commercial scale. Both are called "maguey", like the agaves. In contrast with this, the single representative of the unarmed group Serrulatae that I know as Guatemalan is called "cheech"; this is said by its collector to furnish a sort of crude cordage.

The habitats of both *Agave* and *Furcraea* in Guatemala correspond to what is known of them elsewhere. *Agave,* distinctly northern, represented, as has been said, by its larger section Euagave and usually strongly xerophytic, occurs in gravelly or stony places, on the sides of barrancas, etc., and less commonly on the faces of rocky cliffs than in Mexico. *Furcraea,* a distinctly southern genus, more frequently found in timbered regions, here also affects the wooded adobe hillsides unless, as seems probable, the more xerophytic Serrulatae occur here as to the north in more open and better drained soil.

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[14] Rept. Mo. Bot. Gard. 18: 45. 1907.

SYNOPSIS OF GUATEMALAN AGAVES.

Rather small plants with somewhat fleshy lanceolate to obovate leaves and, so far as known, narrowly oblong panicles with the flowers densely clustered at the ends of their branches.—Indigenous. GUATEMALENSES.

Leaves relatively broad.
- Spine flat-grooved, with acute edges.
  - Very tortuous or twisted, brown. *A. tortispina.*
  - Nearly straight.
    - Gray-brown; teeth heavy. *A. pachycentra.*
    - Chestnut; teeth slender. *A. Hurteri.*
- Spine involute-grooved; teeth small, often on fleshy elevations. *A. Seemanniana.*

Leaves relatively narrow.
- Spine involute-grooved, conical or acicular.
  - Teeth small.
    - Leaves numerous, ascending. *A. Thomasae.*
    - Leaves few, spreading. *A. Deamiana.*
  - Teeth moderate, easily falling. *A. minarum.*
  - Teeth large, brown.
    - Spine long acicular. *A. tenuispina.*
    - Spine heavily conical. *A. opacidens.*
- Spine nearly flat on the face. *A. sicaefolia.*
- Spine round-grooved.
  - Teeth close together, chestnut.
    - Slender-cusped from blue bases. *A. Kellermaniana.*
    - Heavily triangular. *A. samalana.*
  - Teeth widely separated, red-brown. *A. lagunae.*

Rather large plants with fibrous sword-shaped leaves and, so far as known, open panicles with the flowers loosely grouped at the ends of their branches.—Cultivated in hedges or for fiber.

Spine short-conical.—SISALANAE.
- Leaves very glaucous, deeply concave. *A. nivea.*
- Leaves gray-green, nearly flat. *A. sisalana.*

Spine heavy awl-shaped.—TEQUILANAE. *A. Donnell-Smithii.*

Large plants with fleshy lanceolate leaves and open panicles with the flowers rather loosely grouped at the ends of their branches.—Introduced.

Leaves broadly oblanceolate, upcurved at tip.—ATROVIRENTES.
- Spine long-conical, narrowly grooved. *A. tecta.*

Leaves elongated lanceolate, recurving.—AMERICANAE.
- Spine stout-conical, recurved. *A. americana.*
- Spine acicular, straight. *A. picta.*

Agave tortispina n. sp.

Acaulescent, not cespitose. Leaves white-glaucous on a yellow-green ground, more or less transversely banded, forming a close rosette, broadly oblanceolate-spatulate, subacuminate, somewhat concave, slightly granular beneath, 10×25–30 cm.: spine red-brown becoming smoky, glossy, slightly granular below, very tortuous, very openly grooved from above the middle with acute edges, ventrally and dorsally keeled, decurrent for scarcely its own length, somewhat intruded into the green tissue on both faces, 4×30 mm.: teeth similarly colored, 15–25 mm. apart, 3–5 mm. long, nearly straight, broadly triangular, rather gradually dilated into the tops of high green prominences between which the margin is nearly straight, or which are separated by acute sinuses. Inflorescence, flowers and fruit unknown.

Specimens examined: Guatemala. Cruz, between El Rancho and Sanarate (*Trelease, 1,* March, 1915—the type in the herbarium of the University of Illinois).

Agave pachycentra n. sp.

Acaulescent, little suckering. Leaves very blue-glaucous on a deep green ground, ascending in a close rosette, broadly oblong-oblanceolate, acute, concave, minutely granular beneath, 15–20×35–60 cm.: spine drab or graying, dull or slightly glossy, more or less granular, stoutly half-conical or triquetrous, somewhat wavy, very openly grooved from near the end with acute edges, usually ventrally and dorsally keeled, decurrent for about its own length, more or less intruded into the green tissue on both faces, 8×50–60 mm.: teeth similarly colored, rather dull, mostly 25–40 or 50 mm. apart, 5–10 mm. long, more or less curved, especially downward, heavily triangular, abruptly dilated into fleshy prominences or frequently shouldered at base, the intervening margin somewhat concave. Inflorescence, flowers and fruit unknown.

Specimens examined: GUATEMALA. Cruz (*Trelease, 2,* March, 1915—the type in the herbarium of the University of Illinois).

Agave Hurteri n. sp.

Acaulescent, not cespitose. Leaves somewhat glaucous, ascending or outcurving in a rather dense rosette, lance-oblong, rather acute, openly concave, smooth, some 10×75–100 cm.: spine chestnut, glossy above, somewhat pitted below, heavily half-conical, nearly straight, very openly grooved from near the end, usually with median keel, the very acute edges decurrent for about its length, more or less intruded into the green tissues on both faces, about 8×40 mm.: teeth similarly colored, 10–20 mm. apart, 5–10 mm. long, straight or mostly variously curved, the narrowly triangular cusps lenticularly dilated into the straight pale-denticulate margin. Inflorescence about 5 m. high, the upper third or half oblong-paniculate with slender outcurved branches at the ends of which the flowers are densely clustered: bracts narrowly triangular, spreading: pedicels thick, 5–10 mm. long, densely invested by short bracts. Flowers greenish white or pale yellow, 60–70 mm. long: ovary 25–30 mm. long, shorter than the perianth, oblong: tube narrowly conical, 12–15 mm. deep: segments more yellow, 25 mm. long, nearly equaling the ovary: filaments inserted nearly in the throat, 60–70 mm. long, maroon-dotted like the style. Capsules oblong, 20×50 mm., neither stipitate nor beaked: seeds 5×8 mm. Apparently not bulbiferous.

Specimens examined: GUATEMALA. Zunil, on the Samalá River (*Trelease, 3,* April, 1915—the type in the herbarium of the University of Illinois).

Dedicated to Señor Don G. Hurter, of Quezaltenango, who has made exquisite photographs of this and other plants characteristic of this part of Guatemala.

AGAVE SEEMANNIANA Jacobi.

Agave Seemanni Bull, List. 22:3. 1867; also 34:26, 45:18, 49:23. No doubt too incompletely characterized to fix this spelling of the name, which nevertheless is still well established in gardens—*e. g.* Finckh, Gard. 51: 407. *f.* (1897).

A. Seemanniana, Jacobi, Ablandl. Schles. Gesellsch. 1869: 154.

Acaulescent, not cespitose. Leaves glaucous, somewhat green-banded, openly spreading, oblanceolate-oblong or obovate, acute or subacuminate, minutely roughened toward the apex, 8×35 cm.; spine purplish brown, somewhat glossy above, minutely granular below, slenderly conical or acicular, more or less flexuous, involutely grooved from above the middle with acute edges, decurrent for its own length or less, scarcely intruded into the green tissue, 2–4×20–30 mm.: teeth brown or turning gray, 10–20 mm. apart, 2–3 mm. long, rather straight but the lower pointing downwards, the slenderly triangular cusps abruptly dilated onto the tops of fleshy prominences between which the somewhat concave margin sometimes bears slender dark denticles. Inflorescence said by the collector to be 2 m. high. From the illustration of a specimen flowering in Sydney, N. S. W., the inflorescence is 5 m. high, the oblong panicle with densely bunched flowers occupying three-fourths of its length, and the short scape with broad bracts.

Specimens examined: GUATEMALA. Fiscal (*Deam, 6154,* June, 1909). Without data, living plants (Missouri Botanical Garden, 1887; Kew, *no. 271/97,* 1905). A specimen with the spine-base heavier than usual, but referred here, occurs without data in the herbarium of the Missouri Botanical Garden (*Norton, 2,* Feb., 1912), and may be called var. **perscabra.**

That *A. Seemanniana* may have been introduced into cultivation in the form of plants as well as seeds is suggested by Ellemeet's[15] reporting soon after its introduc-

[15] Belgique Horticole. 1871: 118.

tion that a specimen had flowered with him and was still alive a year later. The only other records of its flowering, respectively on the Riviera[16] and in New South Wales,[17] make no mention of this habit of surviving the flowering period; and it is possible that some other species was referred to by M. Ellemeet. That the seedlings at Bull's nurseries were very unlike was noted by Moore;[18] and as early as 1869-70 Bull advertised, with fair characterization, in addition to his typical *Seemanni* the varieties *acuta, papillosa* and *parvispina.* In the list of his own plants published in 1878, Peacock also mentions a variety *rotundifolia* of *A. Seemannii* as he calls it.

As has been stated above, *A. Seemanniana* seems to have Segovia, Nicaragua as its type locality, and so is to be sought in the mountains between this locality and the Motagua valley in Guatemala.

Agave Thomasae n. sp.

Acaulescent, suckering freely. Leaves clear green with dense easily removable striate bloom, ascending with outcurved tip, spatulate-oblanceolate, acute or somewhat acuminate, rather thin and flexible, concave, smooth above, finely roughened beneath, some 15×60 cm.: spine chestnut, somewhat roughened, acicular, nearly straight, involutely grooved below the middle with acute edges, little decurrent or intruded into the green tissue, 2×25 mm.: prickles chestnut, 5–10 mm. apart, 1–2 mm. long, nearly straight, the extremely slender cusps slightly dilated at base, the straight intervening margin with numerous minute needle-like denticles. Inflorescence, flowers and fruit unknown.

Specimens examined: Cultivated at the Hotel

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[16] Baker, Kew Bull. 1892: 4; Add. Ser. 2: 220.
[17] Finckh, Garden. 51: 407. *f.* 1897.
[18] T. M., Gard. Chron. 1871: 74.

Thomas, Quezaltenango (*Trelease, 19,* April, 1915—the type).

Thinner-leaved and smaller-toothed than the Guatemalenses as otherwise known, and resembling certain of the Mexican aloid Littaeas—to which it may prove ultimately to belong. It is said to have come from the Guatemalan mountains, and is dedicated to Señora Dora Thomas, the possessor of the type plant.

Agave Deamiana n. sp.

Acaulescent, scarcely suckering. Leaves grayish or lightly glaucous, widely spreading, oblanceolate, acute, more or less concave, minutely roughened especially on the back and margin, some 10×100 cm.: spine purplish brown, somewhat glossy above, minutely granular below, slenderly conical or acicular, more or less flexuous, involutely grooved from about the middle with acute edges, decurrent for about its own length, scarcely intruded into the green tissue, 3–4×40 mm.: teeth chestnut, 10–20 mm. apart, 2–4 mm. long, straight or curved, especially downward, the slender triangular cusps lenticularly dilated into the straight margin. Inflorescence, flowers and fruit unknown.

Specimens examined: Guatemala. Sides of ravines, Fiscal (*Deam, 6154 a*—the type in the herbarium of the Missouri Botanical Garden; *6199, 6201;*—all in June, 1909).

Agave minarum n. sp.

Acaulescent, scarcely cespitose. Leaves yellow-green, loosely spreading, lanceolate, acute, smooth, some 6×60 cm.: spine brown, glossy above, conical, smooth, nearly straight, round-grooved above becoming involute as the leaf dries, decurrent for rather more than its own length and somewhat dorsally intruded into the green tissue, 5×45 mm.: teeth easily detachable, 5–10 mm. apart, the intervening margin straight. Inflorescence 2 or 3 m.

high, loosely few-branched above with the flowers rather less compact than usual at ends of the slender spreading branches: pedicels 2×10 mm. Flowers yellow, 40 mm. long: ovary 20 mm. long, equaling the perianth, oblong-fusiform: tube conical, 6 mm. deep: segments 14 mm. long, shorter than the ovary: filaments inserted about the middle of the tube, some 30 mm. long, twice as long as the segments. Fruit unknown.

Specimens examined: Guatemala. Sierra de las Minas, opposite El Rancho, at 2000 ft. altitude (*Kellerman, 5129,* March, 1905—the type, as sheet *no. 576,279* in the U. S. National Herbarium). What is taken for the same species occurs on the rocks along the Motagua River about San Pablo, below Gualan.

Agave tenuispina n. sp.

Acaulescent, scarcely cespitose. Leaves glaucous, forming a rather compact rosette, oblanceolate, acute, smooth, about 20×70 cm.: spine dull brown, acicular, smooth or somewhat roughened at base, slightly undulate, involutely grooved from above the middle with rather blunt edges, decurrent for scarcely half its length and not intruded into the green tissue, 3×60–70 mm.: teeth brown, somewhat glossy, 20–40 mm. apart, 5–10 mm. long, curved in either direction, rather narrowly triangular, somewhat deltoidally enlarged into fleshy prominences between which the margin is somewhat concave, or into the otherwise nearly straight margin. Inflorescence, flowers and fruit unknown.

Specimens examined: Guatemala. Mountainsides at Cruz (*Trelease, 4,* March, 1915—the type in the herbarium of the University of Illinois).

Agave opacidens n. sp.

Acaulescent, scarcely suckering. Leaves glaucous, lanceolate, acute, roughened on the back and margin,

8–10×75 cm.: spine dull brown, quickly graying, granular below, stoutly triquetrous-conical, nearly straight, involutely grooved from above the middle with acute edges, decurrent for once or twice its length, somewhat dorsally intruded into the green tissue, 3–6×50–60 mm.: teeth drab, rather dull, 20–50 mm. apart, 5–8 mm. long, nearly straight, heavily triangular, dilated lenticularly into more or less elevated prominences of the otherwise nearly straight margin. Inflorescence about 5 m. high, the upper half oblong-paniculate: bracts broadly triangular, appressed: pedicels about 10 mm. long. Flowers yellow, 40–45 mm. long: ovary 25–30 mm. long, rather exceeding the perianth, fusiform: tube openly conical, 10 mm. deep: segments 5×12–15 mm., half as long as the ovary: filaments inserted about the middle of the tube, 35 mm. long. Capsules oblong, stipitate, 20×40–45 mm.: seeds 5×6 mm. Apparently not bulbiferous.

Specimens examined: Guatemala. Cruz (*Trelease, 5,* March, 1915—the type in the herbarium of the University of Illinois).

Agave sicaefolia n. sp.

Acaulescent, very cespitose. Leaves gray-green rather than glaucous, forming a dense cluster, lanceolate, acute or slightly acuminate, nearly flat to deeply concave, slightly granular on the back above, 7–8×60–75 cm.: spine purplish chestnut fading to gray-brown, rather glossy, granular below, triquetrous, nearly straight, flattened or very openly grooved, often with median keel, from near the very sharp end, with acute short-decurrent margin, somewhat intruded into the green tissue both dorsally and ventrally, 4×30–40 mm.: teeth similarly colored, somewhat glossy, 15–35 mm. apart, 3–5 mm. long, mostly upcurved, the rather slender sometimes hooked cusps lenticularly dilated, the rather concave intervening margin sometimes with one or more

minute brown needles. Inflorescence, flowers and fruit unknown.

Specimens examined: GUATEMALA. Hillside at El Rancho (*Trelease, 6,* April, 1915,—the type in the herbarium of the University of Illinois).

Agave Kellermaniana n. sp.

Acaulescent. Leaves very glaucous, elongated-lanceolate, slightly acuminate, rather concave, somewhat minutely granular on the back above, 8–10×100 cm. or more: spine purplish chestnut, somewhat glossy, granular below, slenderly conical, sometimes slightly flexuous, round-grooved from above the middle with rather blunt edges, decurrent for once or twice its length, somewhat dorsally intruded into the green tissue, 4–5×30–35 mm.: teeth 10–25 mm. apart, 3–5 mm. long, upcurved, the rather slender glossy purple-chestnut cusps with abrupt blue bases either occupying the larger part of fleshy prominences or lenticular in the straight margin. Inflorescence, flowers and fruit unknown.

Specimens examined: GUATEMALA. Sides of ravines, at 3700 ft., Fiscal (*Deam, 6239,* June, 1909—the type, at the Missouri Botanical Garden). Without data (*Norton,* 1912).

Agave samalana n. sp.

Acaulescent, scarcely suckering. Leaves glaucous, especially beneath, rather numerous, oblanceolate, subacuminate, somewhat concave, minutely roughened beneath and on the margin, finally some 15×60 cm.: spine reddish becoming darker, somewhat glossy, typically granular below, slenderly conical or acicular, nearly straight, round-grooved from above the middle with acute edges, decurrent for something like its own length, more or less intruded into the green tissue dorsally, 3–4 ×35–55 mm.: teeth chestnut, dull, 5–10 or 20 mm. apart, 1–3 or 5 mm. long, straight or gently upcurved, trian-

gular, rather lenticularly widened into the nearly straight denticulate margin. Inflorescence 3–4 m. high, the upper half narrowly paniculate with extremely short branches. Flowers (?). Capsules oblong, 2×5–6 cm., campanulately dehiscent, reticulate: seeds 5×7 mm.

Specimens examined: GUATEMALA. Mountainsides along the Samalá River about Esperanza, between Sta. Maria and Zunil (*Trelease, 7, 9,* April 10, 1915—the types in the herbarium of the University of Illinois; *8,* April 4, 1915).

Agave lagunae n. sp.

Acaulescent, scarcely suckering. Leaves very glaucous, spreading, lanceolate, acute, moderately concave, more or less minutely granular on the back and margin, 8–10×30–40 cm.: spine garnet, glossy, granular below, conical, often slightly flexuous, round-grooved from near the very sharp tip with acute shortly decurrent edges, somewhat dorsally intruded into the green tissue, 3–5×20–30 mm.: teeth similarly colored, glossy, 20–40 mm. apart, 3–5 or 6 mm. long, mostly upcurved above and partly recurved below, the rather slender mostly hooked cusps lenticularly widened into the margin or on the tops of fleshy prominences between which the margin is nearly straight. Inflorescence, flowers and fruit unknown.

Specimens examined: GUATEMALA. Above Amatitlan, near the lake (*Trelease, 10,* April, 1915—the type, in the herbarium of the University of Illinois). Palin to Escuintla (*De Ham,* 1908; *Kradolfer,* 1908).

On gravel, talus and cliffs, in the region between Amatitlan and Palin on the flanks of the Volcan de Agua, on the Pacific slope.

Agave nivea n. sp.

Acaulescent, suckering. Leaves very glaucous, somewhat transversely green-banded, narrowly lanceolate,

ascending, acute, very concave so as to appear oblong, minutely granular on the back and margin, at length 15×200 cm.: spine black-chestnut, somewhat glossy, finely pitted, slenderly conical, more or less laterally curved, very shallow grooved near the base, 3×15–20 mm., scarcely decurrent or intruded: teeth similarly colored, rather glossy above, 30–50 mm. apart, about 3 mm. long, mostly upcurved, the often curved or flexed slender cusps deltoidally broadened below and often from somewhat raised fleshy bases between which the margin is nearly straight. Inflorescence said to be an open panicle of yellowish flowers accompanied or followed by bulbils.

Specimens examined: GUATEMALA. About El Rancho (*Trelease, 11,* April, 1915—the type in the herbarium of the University of Illinois; *12, 13*).

Known to me only as planted in hedge-rows or clearly escaped, but said to be spontaneous in the mountains to the north: perhaps really of the endemic alliance.

AGAVE SISALANA Perrine.

Agave sisalana Perrine, House Doc. no. 564:8; Senate Doc. no. 300:36. *pl. 1-2.* 1838.—This species is contrasted with its immediate relatives in Mem. Nat. Acad. Sci. 11: 47. 1913.

Subacaulescent, suckering. Leaves sword-shaped, lightly glaucous becoming green: spine chestnut, pitted, tumidly conical, gently recurved, shallowly round-grooved toward the base, neither decurrent nor intruded into the green tissue: teeth small and slender or typically nearly or quite wanting, the margin nearly straight.

The Sisal, yaxci or green agave, here called henequen and occasionally planted for its fiber, *e. g.,* Cruz (*Trelease, 14*): originally from Yucatan.

Agave Donnell-Smithii n. sp.

Acaulescent, suckering freely. Leaves light green

and somewhat whitened above, glaucous beneath, ascending, sword-shaped, moderately concave, smooth, 8× 75–100 cm. or longer: spine garnet becoming chestnut, glossy, smooth, stoutly awl-shaped, slightly curved, terete, flat or shallow-grooved near the base, neither decurrent nor intruded into the green tissue, 4×12–15 mm.: teeth similarly colored, 10 or 15–25 or 30 mm. apart, 2–3 mm. long, upcurved, triangular, lenticularly dilated into the straight margin. Inflorescence paniculate: pedicels 5–10 mm. long. Flowers greenish yellow, 40–45 mm. long; ovary 20–25 mm. long, about equaling the perianth, oblong-fusiform: tube suburceolate, some 8 mm. deep: segments 15–20 mm. long, shorter than the ovary, brighter colored than the tube: filaments inserted above the upper third of the tube, 35 mm. long, twice as long as the segments. Fruit unknown. Bulbiferous(?).

Specimens examined: Guatemala. Hedges about Escuintla (*Smith, 2085*—the type in the U. S. National Herbarium; *Trelease, 15,* 1915). Mixco (*Trelease, 16,* 1915). Fiscal (*Deam, 6240,* June, 1909). Also seen in cultivation in the Plaza de Armas, Guatemala City, at Guarda Viejo, and on the Pacific slope as far down as Palo Gordo near Mazatenango.

Apparently of the alliance of *A. tequilana* and *A. Zapupe* of Mexico, and of doubtful origin; but the Fiscal specimens, from ledges in a cañon, should be wild. The group is not unknown in the Pacific region to the South.

Agave tecta n. sp.

Acaulescent, suckering. Leaves grayish green, broadly oblanceolate or at first almost obovate, ascending, the gradually subacuminate apex sigmoidally upcurved, concave, valleculate above, smooth, becoming 50×200 cm.: spine purple-chestnut becoming gray, dull, smooth, conical or subacicular, often compressed, slightly flexuous, shallowy grooved below the middle, 5–7×45–65 mm.,

long-decurrent, somewhat intruded dorsally into the green tissue: teeth similarly colored, more or less polished, 40–70 mm. apart, about 8 mm. long, recurved, the triangular often curved cusps abruptly dilated into low bases 15 mm. or more wide, between which the smooth margin is nearly straight. Inflorescence 5–6 m. high, the upper half ellipsoidally paniculate with slightly ascending branches: bracts broadly triangular, densely imbricated so as to cover the scape completely, those of the panicle reduced and spreading: pedicels thick, 5–10 mm. long. Flowers yellow, about 70 mm. long: ovary 30–35 mm. long, about equaling the perianth, oblong: tube openly conical, 10–15 mm. deep: segments about 20 mm. long, shorter than the ovary: filaments inserted about the middle of the tube, some 40 mm. long. Capsules (immature) oblong, some 30×60 mm. Apparently not bulbiferous.

Specimens examined: Guatemala. About Quezaltenango (*Trelease, 17*—the type, in the herbarium of the University of Illinois; *18,* both in April, 1915).

Known to me only as planted in hedge-rows, sparingly in the vicinity of Mixco, between Antigua and the capital—and in gardens in the latter, but abundantly in and about Quezaltenango, north of which it is said to occur wild in the mountains. Evidently of the group Atrovirentes, to which the pulque species of Mexico belong,—the type of which, *A. atrovirens,* like *Furcraea longaeva,* was described from Mt. Tanga in southern Oaxaca.

Though pulque is now unknown in Guatemala, Fuentes y Guzman, "regido perpetual de la ciudad de Goathemala," records that excellent pulque was produced at Atmolonga or Ciudad Vieja and at San Gaspar two centuries ago;[19] but there remains no evidence of it that I have been able to discover unless it be in these scattered hedge-rows of *Agave tecta.*

[19] Fuentes y Guzman, Recordacion Florida. 1: 289. Madrid, 1882,—the manuscript written in 1690.

AGAVE AMERICANA L.

Leaves lanceolate, narrowly so in age, usually hooked toward the end, gray-green: spine stoutly conical, gently recurved, narrowly grooved below the middle, scarcely decurrent: teeth narrowly triangular, hardened into the tops of fleshy prominences between which the margin is more or less concave.

The most frequently planted *Agave,* in Guatemalan parks represented by the white- or yellow-margined variety, var. *marginata.*

AGAVE PICTA Salm.

Differing from *A. americana marginata* in its darker green leaves and slender acicular straight spine.

The unvariegated form of this, which occurs about the Mediterranean from seeds of the variegated form, has been called *A. ingens* by Mr. Berger: it is not known elsewhere.

The variegated form is sparingly cultivated in Guatemala,—*e. g.* about the railroad yards in the capital.

SYNOPSIS OF GUATEMALAN FURCRAEAS.

Leaves rough-margined but without large teeth, glaucous, striate-roughened. Caulescent.—SERRULATAE.

Tall tree. Flowers pubescent. *F. longaeva.*
Scarcely 2 m. high. Flowers glabrous. *F. quicheensis.*

Leaves smooth-margined, toothed, green or little glaucous, not striate. Often acaulescent.—EUFURCRAEA.

Teeth usually confined to the lower third of leaf. *F. samalana.*
Toothed throughout.
Teeth red or brown, rather distant. Leaves flattish. *F. guatemalensis.*
Teeth blackish, close together. Leaves very concave. *F. melanodonta.*

FURCRAEA LONGAEVA Karwinski & Zuccarini.

Furcraea longaeva Zuccarini, Acta Acad. Caes. Leop.-Carol. 16[2]: 665. *pl. 48.* 1833.—As with other species, the generic name is variously spelled *Furcraea, Furcroea* and *Fourcroya;* and the specific name has been transformed into *longa* by Smith, Teysmannia. 7: 131. 1897.

Arboreous, the unbranched trunk becoming 15 m. or more high. Leaves gray, outcurved, lanceolate, subacuminate, concave, 8–15×200 cm., minutely rough-margined. Inflorescence 5 m. high, broadly conical, short-stalked. Flowers 30–40 mm. long: ovary 20–25 mm. long, rather longer than the perianth. Capsules oblong, narrowed below: seeds 4×6 mm. Bulbils unknown.

Said to have been found by Skinner in the high mountains of Guatemala many years ago. The type was from Mt. Tanga, Oaxaca, at an altitude of 9,000–10,000 ft., and Purpus has rediscovered it on the Cerro de Besetla, in the Sierra de Mixteca, on the boundary between the Mexican states of Puebla and Oaxaca.

Furcraea quicheensis n. sp.

Caulescent, the sometimes branched trunk little over 1 m. high. Leaves very pale green, heavily pruinose, lanceolate, acute, smooth, 10×120 cm., the thin subcartilaginous margin roughened at intervals of 1–2 mm. by minute straight yellowish denticles. Inflorescence 2.5–5 m. high, scarcely 1 m. wide with much reduced lower branches, subsessile (?): pedicels 7–10 mm. long, once or twice surpassed by the subtending bracts. Flowers 50–60 mm. long: ovary 25–30 mm. long, equaling the perianth: segments 6-8×25-30 mm., white-margined: filaments 10–12 mm. long. Capsules (immature) very narrowly oblong, 30×100–120 mm.: seeds and bulbils unknown.

Specimens examined: GUATEMALA. Between Quiché and Totonicapan (*Cook, n. b. 421,* May 17, 1906—the type, in the U. S. National Herbarium as sheet *number 692,146*).

Furcraea samalana n. sp.

Acaulescent or caulescent with the trunk as much as 2 m. high. Leaves green or very slightly grayish, lanceolate, acute, nearly smooth, channeled with broad flat or outcurved margins, 10–15×150–200 cm.: spine scarcely 1×2 mm., acute, commonly abortive: teeth red-brown, usually absent or greatly reduced on the very long-acute upper part, 10–25 or 30 or even 60 mm. apart, slender, some 4 mm. long, mostly upcurved, decurrent on fleshy elevations between which the margin is concave when they are close together. Inflorescence 5 m. high, the upper three-fourths loosely oblong-paniculate. Flowers said to be greenish yellow. Capsules and seeds (?). Bulbils abundant, conical-ovoid, leafy-tufted, with dull gray-green scales.

Specimens examined: Guatemala. Samalá valley, between Sta. Maria and Zunil, etc. (*Trelease, 20,* April, 1915—the type in the herbarium of the University of Illinois; *21, 22, 29*).

Furcraea guatemalensis n. sp.

Subacaulescent. Leaves rather dull green above and grayish beneath, lanceolate to typically almost sword-shaped, acute, smooth or very slightly roughened, moderately concave with somewhat outcurved margins, 10–15×200–225 cm.: spine scarcely 1×2 mm., awl-shaped: teeth red-brown, at first pale at base, later approaching chestnut, 10–25 or 30 mm. apart, some 3 mm. long, upcurved, decurrent on moderate fleshy elevations between which the margin is nearly straight. Inflorescence 5 m. high, loosely paniculate where exserted, glabrate. Flowers said to be greenish white. Capsules round-cuboid, stipitate and beaked, 50×50 mm.: seeds 12×20 mm. Bulbils abundant, round-ovoid, not leafy-tufted, the dark green scales very glossy.

Specimens examined: Guatemala. Guarda Viejo (*Trelease, 23,* April, 1915—the type in the herbarium of the

University of Illinois). Outskirts of Guatemala City (*Trelease, 24*). Palin (*Trelease, 25, 30*). Fiscal (*Deam, 6107, 6176-7*). Agua Caliente (*Deam, 6149*).

Furcraea melanodonta n. sp.

Caulescent, the trunk scarcely over 1 m. high. Leaves gray or bluish on both faces, narrowly lanceolate, acute, slightly rough on both faces, deeply concave, 7–8×150 cm. or more: spine scarcely 2×2 mm., blunt, grooved at base, slightly decurrent: teeth blackish chestnut, 10 or 15 or sometimes 20 mm. apart, 5 mm. long, strongly upcurved, decurrent on fleshy elevations between which the margin is concave. Inflorescence, flowers, capsules and bulbils unknown.

Specimens examined: GUATEMALA. Cruz (*Trelease, 26,* March, 1915—the type in the herbarium of the University of Illinois).

EXPLANATION OF ILLUSTRATIONS.

Plate VI.—*Agave tortispina.* Above, the type at Cruz, Guatemala, with a small planted specimen of *A. sisalana* in the background, ×1/7. Below, spines and margin from the type (*Trelease, 1*), natural size.

Plate VII.—*Agave pachycentra.* Above, the type at Cruz, Guatemala, ×1/10. Below, spines and margin from the type (*Trelease, 2*), natural size.

Plate VIII.—*Agave Hurteri.* The type plant and two other flowering specimens, in the Samalá valley at Zunil, Guatemala, ×1/50.

Plate IX.—*Agave Hurteri.* Above, a panicle branch, showing the congested flowers characteristic of the Guatemalenses, ×1/3. Below, split and entire flowers, natural size. Both from the type (*Trelease, 3*).

Plate X.—*Agave Hurteri.* Spines, leaf-margin, capsules and seeds, from the type (*Trelease, 3*), natural size.

Plate XI.—*Agave Seemanniana.* Apex, margin and additional spines of the Guatemalan plant taken for this species (*Deam, 6154*), natural size.

Plate XII.—*Agave Thomasae.* Above, the type plant, at the Hotel Thomas, Quezaltenango, Guatemala—with a young plant of *A. americana marginata* in the foreground, ×1/15. Below, spine and prickles of the type (*Trelease, 19*), natural size.

Plate XIII.—*Agave Deamiana.* Above, representative plant, at Fiscal, Guatemala (*Deam*, photograph *6199*), ×1/15. Below, apex and margin of the type (*Deam, 6154 a*), natural size.

Plate XIV.—*Agave minarum.* Type sheet, reduced; and flowers of the type (*Kellerman, 5129*), natural size.

Plate XV.—*Agave tenuispina.* Type sheet, reduced; and spines and leaf-margin of the type (*Trelease, 4*), natural size.

Plate XVI.—*Agave opacidens.* Above, spines and leaf-margin. Below, dried flowers, capsules and seeds. Both from the type (*Trelease, 5*), natural size.

Plate XVII.—*Agave sicaefolia.* Above, the type clump at El Rancho, Guatemala. Below, spines and leaf-margin from the type (*Trelease, 6*), natural size.

Plate XVIII.—*Agave Kellermaniana.* Type sheet, reduced; and spine and leaf-margin of the type (*Deam, 6239*), natural size.

Plate XIX.—*Agave samalana.* Above, the type group of plants, ×1/100. Below, a representative plant, ×1/20. Between Zunil and Sta. Maria, in the Samalá valley, Guatemala.

Plate XX.—*Agave samalana.* Above, spines and leaf-margin, from the type (*Trelease, 7*). Below, shriveled flowers, capsules and seeds, from the type (*Trelease, 9*). Both natural size.

Plate XXI.—*Agave lagunae.* Above, the type plant on a gravelly slope above Amatitlan, Guatemala, ×1/10. Below, spines and leaf-margin from the type (*Trelease, 10*). Both natural size.

Plate XXII.—*Agave nivea.* Above, type plants in a hedgerow at El Rancho, Guatemala, ×1/30. Below, spines and leaf-margins from the type (*Trelease, 11*), natural size.

Plate XXIII.—*Agave Donnell-Smithii.* Plant in a hedge at Escuintla, Guatemala.

Plate XXIV.—*Agave Donnell-Smithii.* Above leaf arming from the type (*Smith, 2085*). Below, spines and portion of leaf from the plant pictured in *pl. 23* (*Trelease, 15*). Both natural size.

Plate XXV.—*Agave Donnell-Smithii.* Fragment of a panicle branch from the type (*Smith, 2085*), natural size.

Plate XXVI.—*Agave tecta.* Type group of plants in a hedgerow at Quezaltenango, Guatemala: the upper, ×1/60; the lower, ×1/30.

Plate XXVII.—*Agave tecta.* Spines, leaf-margins, bud, and imperfectly developed flowers, from the type (*Trelease, 17*—shown above in *pl. 26*), natural size.

Plate XXVIII.—*Furcraea longaeva.* A representative group of trees in the Mexican state of Oaxaca. Photographed by Dr. C. A. Purpus.

Plate XXIX.—*Furcraea quicheensis.* Flowers, and portion of leaf, of the type (*Cook, n. b. 421*), natural size.

Plate XXX.—*Furcraea samalana.* A flowering plant, in the vicinity of Quezaltenango, Guatemala. Photographed by Mr. G. Hurter.

Plate XXXI.—*Furcraea samalana.* Leaf-tips and margins, from the type (*Trelease, 20*), and bulbils, from a plant below Sta. Maria, Guatemala (*Trelease, 29*), natural size.

Plate XXXII.—*Furcraea guatemalensis.* The type plant, in a hedgerow near Guarda Viejo, Guatemala.

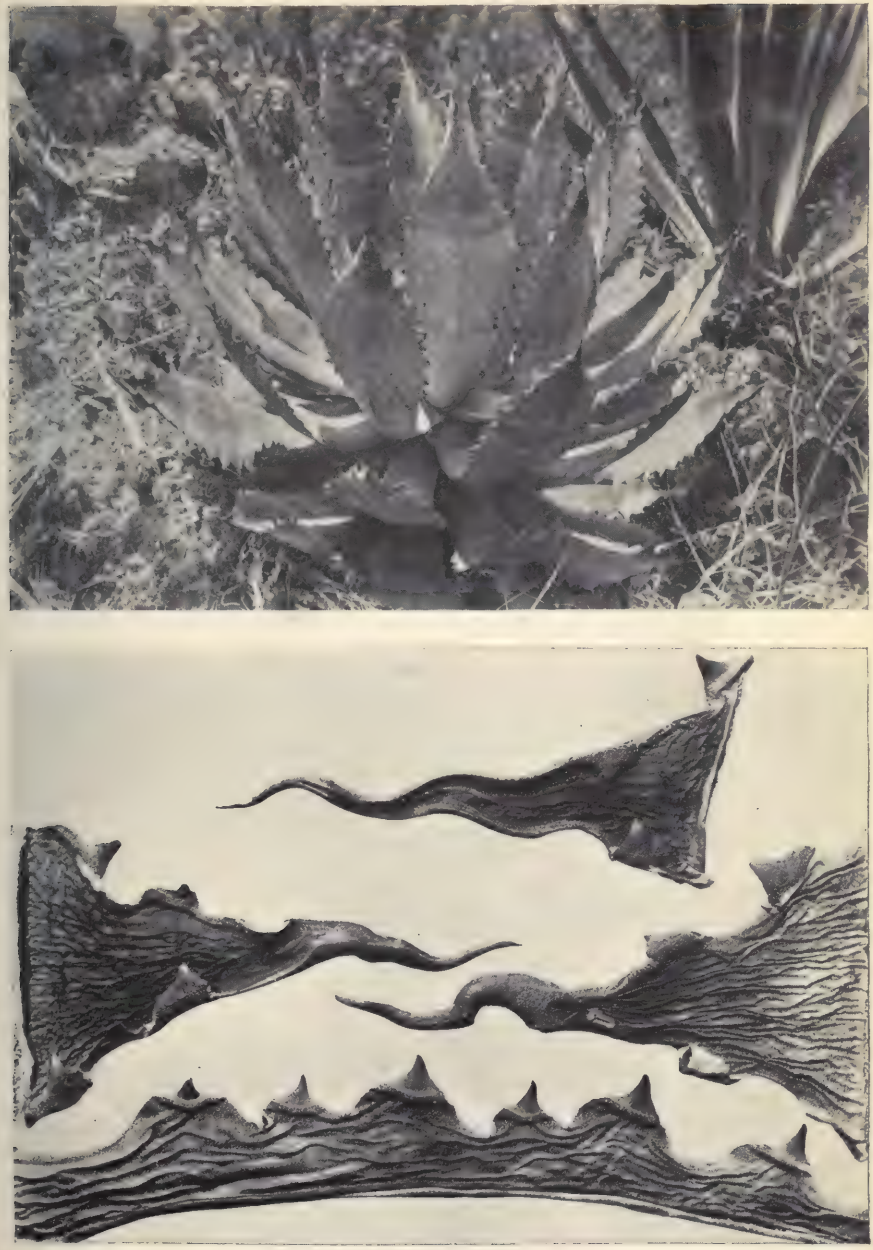
PLATE XXXIII. *Furcraea guatemalensis.* Above, plant growing on a steep hillside, showing the upcurving leaves, Guatemala City. Below, leaf-tips and margin, from the type (*Trelease, 23*), natural size.

Plate XXXIV.—*Furcraea guatemalensis.* Capsules, seeds and bulbils, natural size. Palin, Guatemala (*Trelease, 30*).

Plate XXXV.—*Furcraea melanodonta.* Above, the type group, at Cruz, Guatemala. Below, leaf-tips and margin, from the type (*Trelease, 26*), natural size.

The University of Illinois, June 2, 1915.

Issued July 15, 1915.



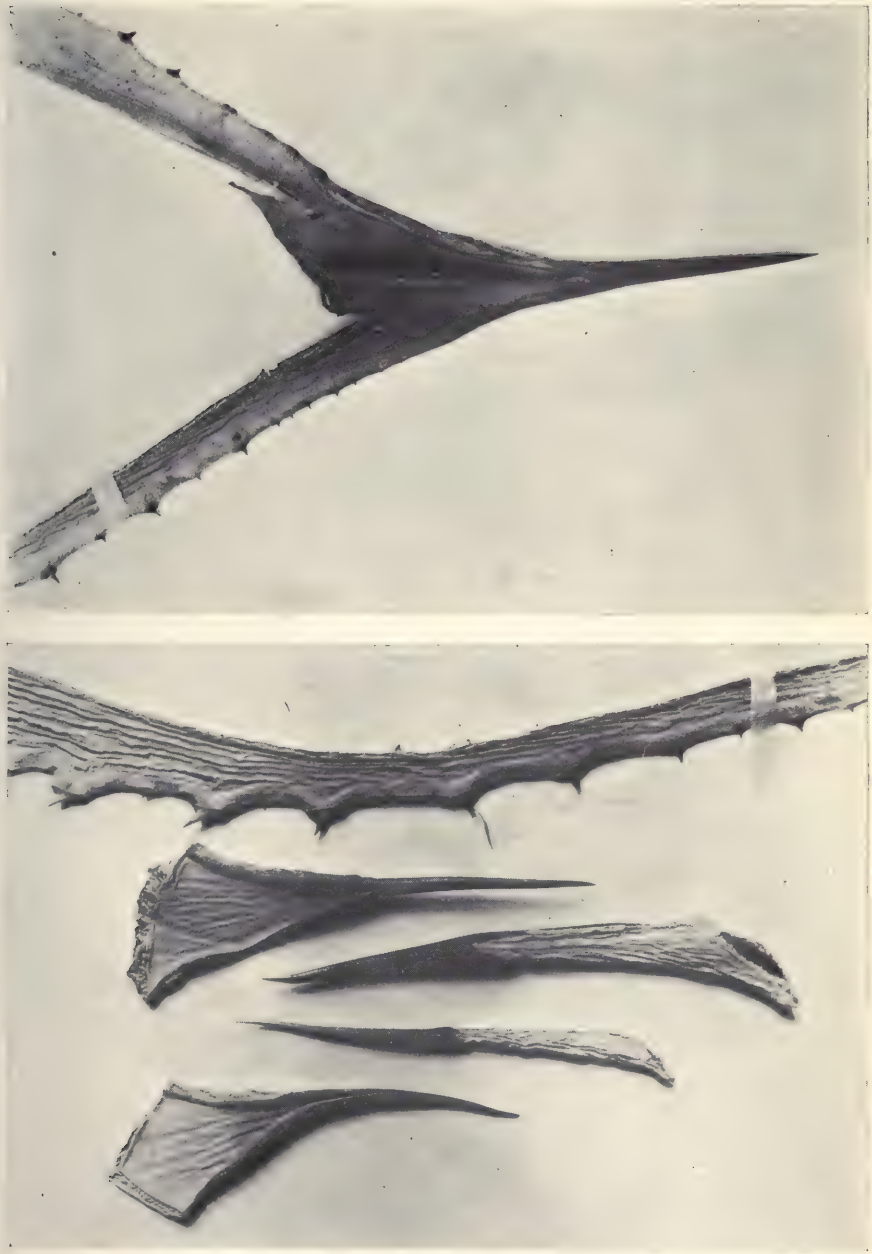
AGAVE TORTISPINA.

AGAVE PACHYCENTRA

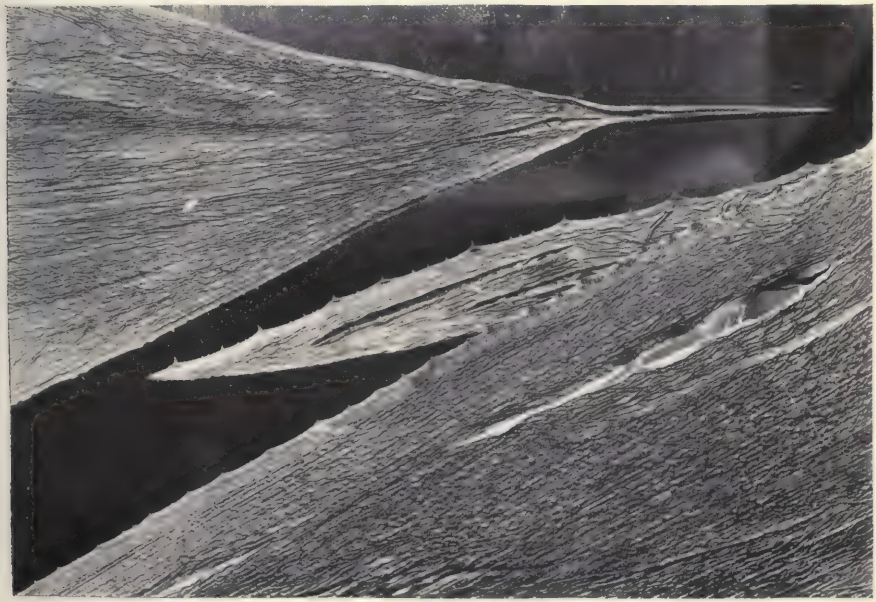
AGAVE HURTERI.

AGAVE HURTERI.

AGAVE HURTERI.



AGAVE SEEMANNIANA.

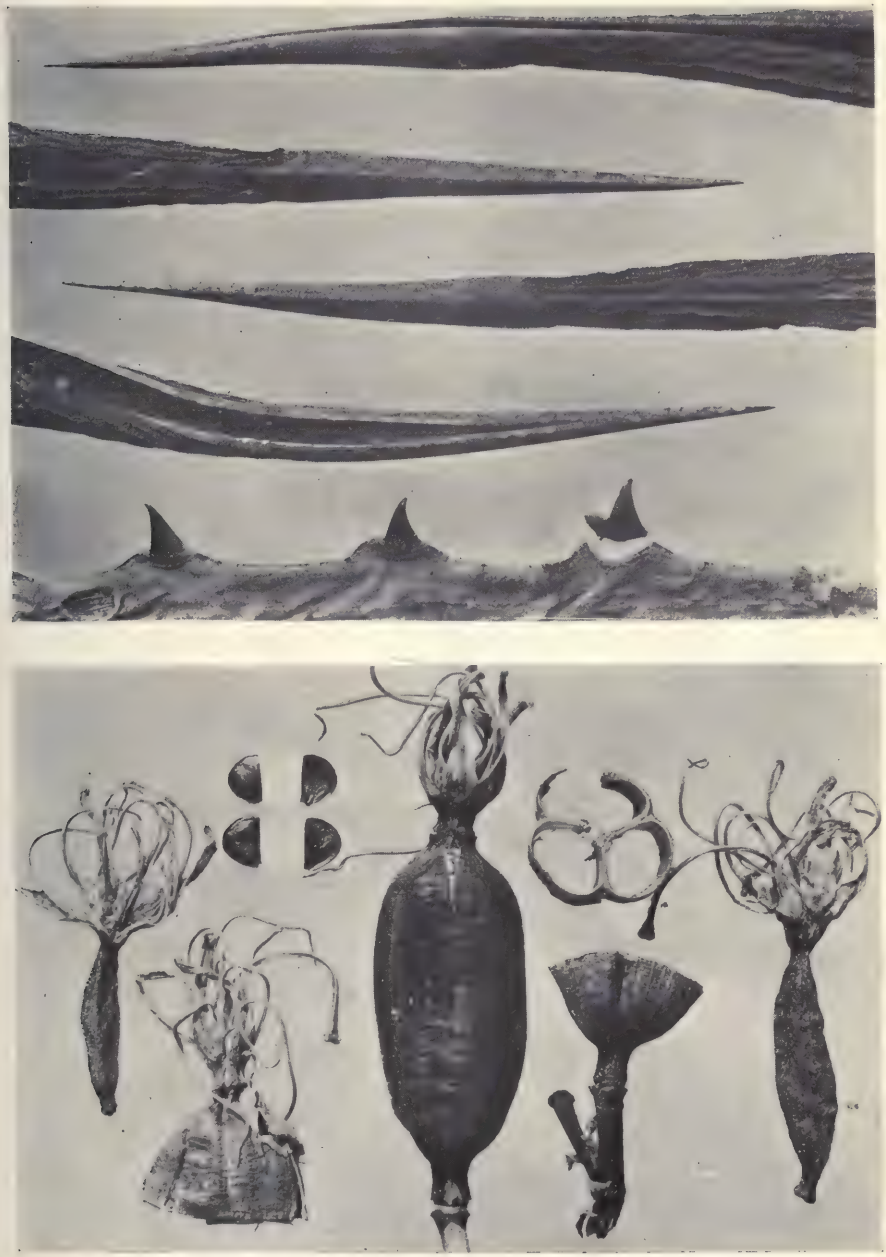


AGAVE THOMASAE.

AGAVE DEAMIANA.

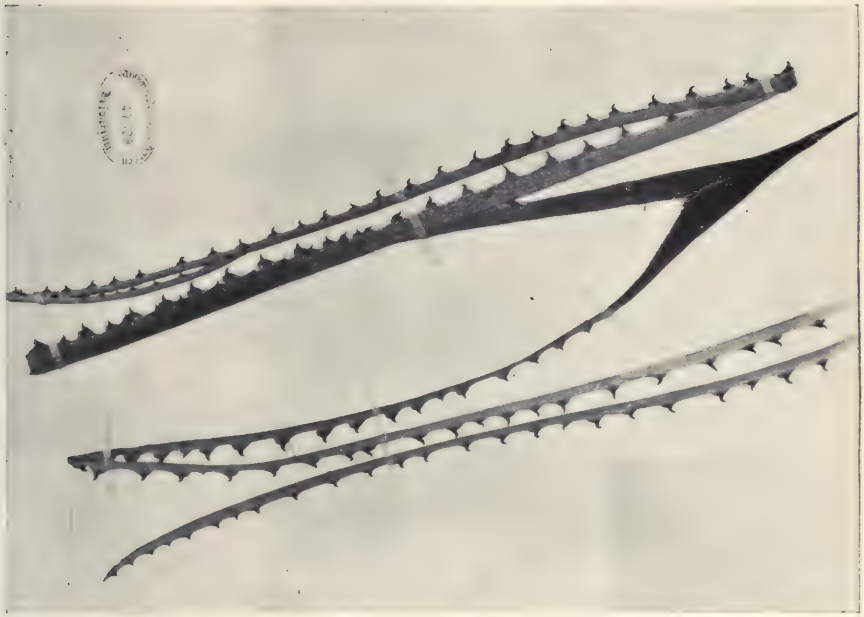
AGAVE MINARUM.

AGAVE TENUISPINA.



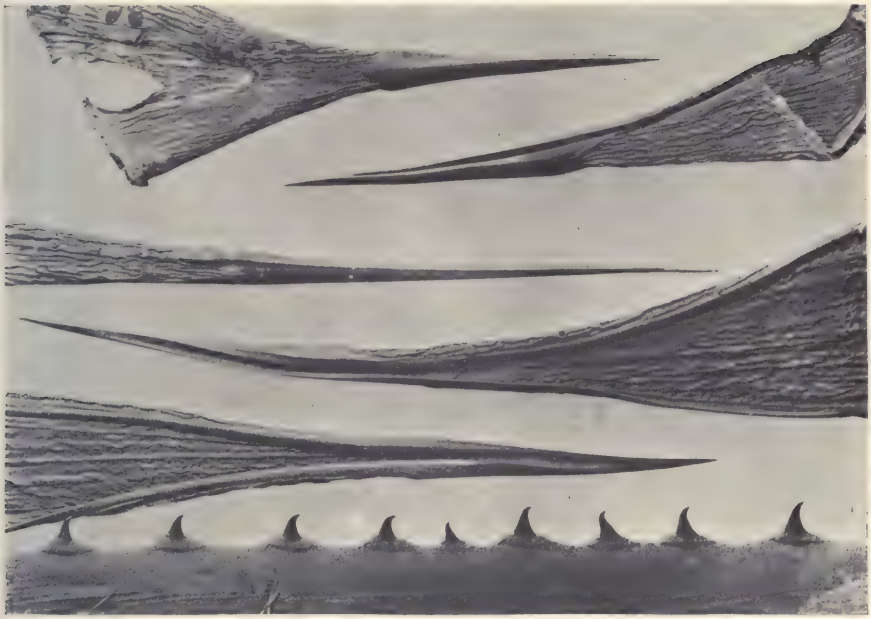
AGAVE OPACIDENS.

AGAVE SICAEFOLIA.



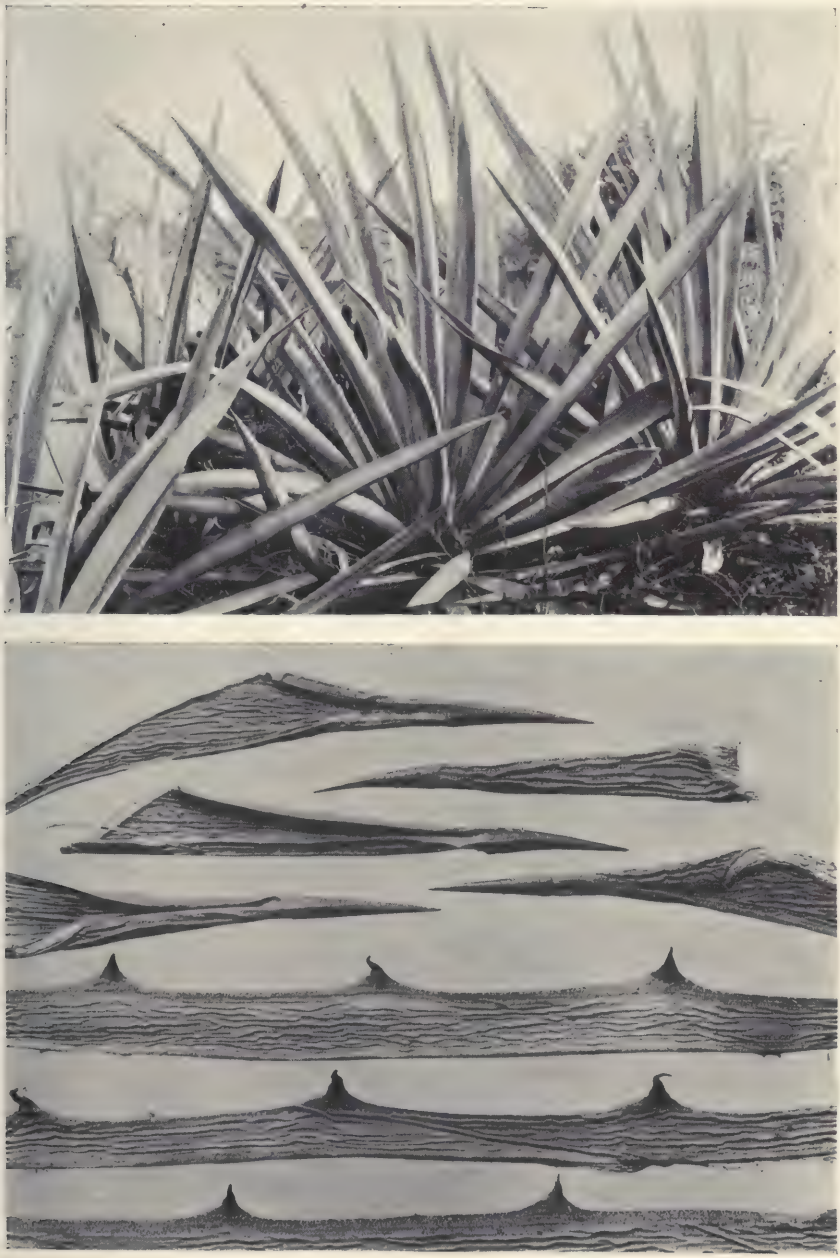
AGAVE KELLERMANIANA.

AGAVE SAMALANA.



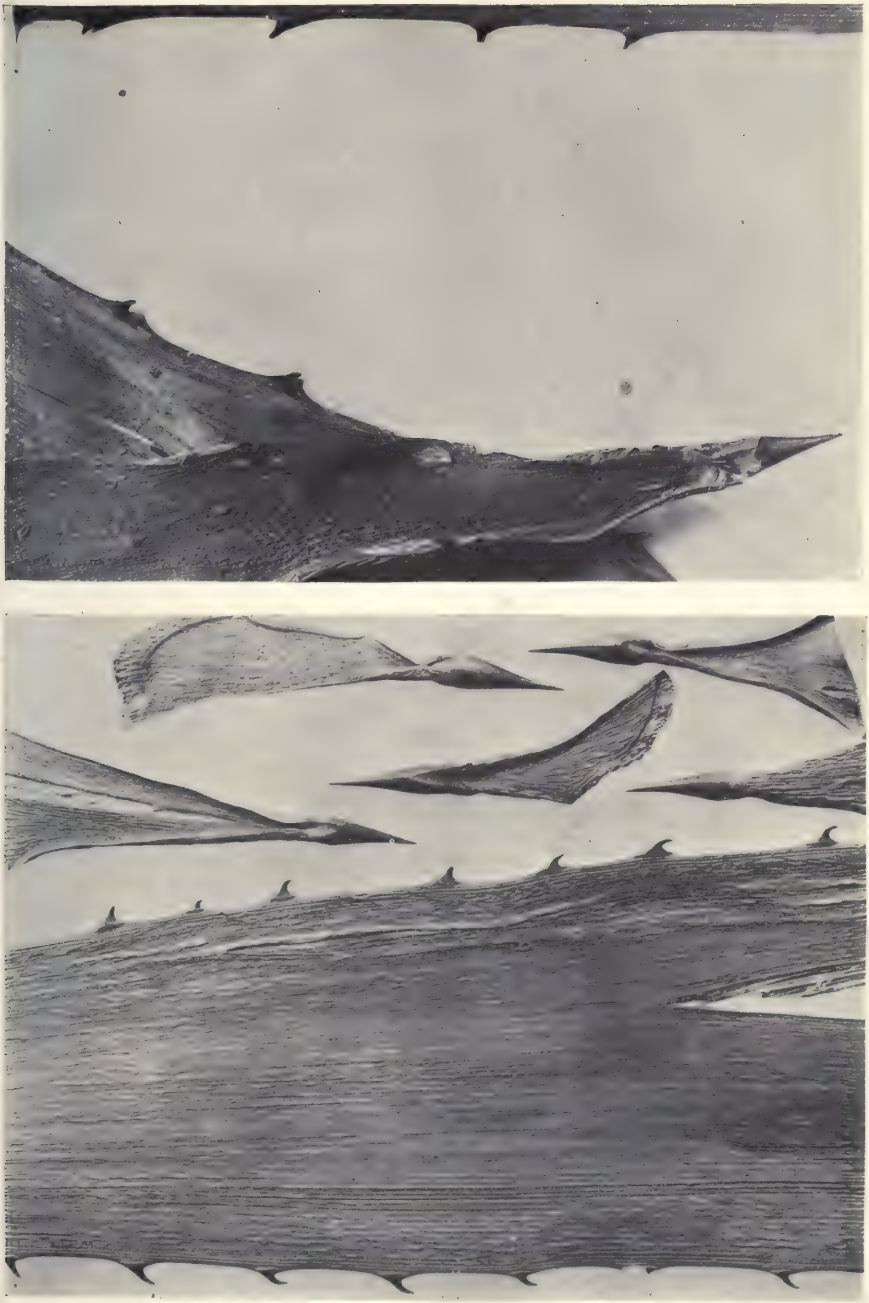
AGAVE SAMALANA.

AGAVE LAGUNAE.



AGAVE NIVEA.

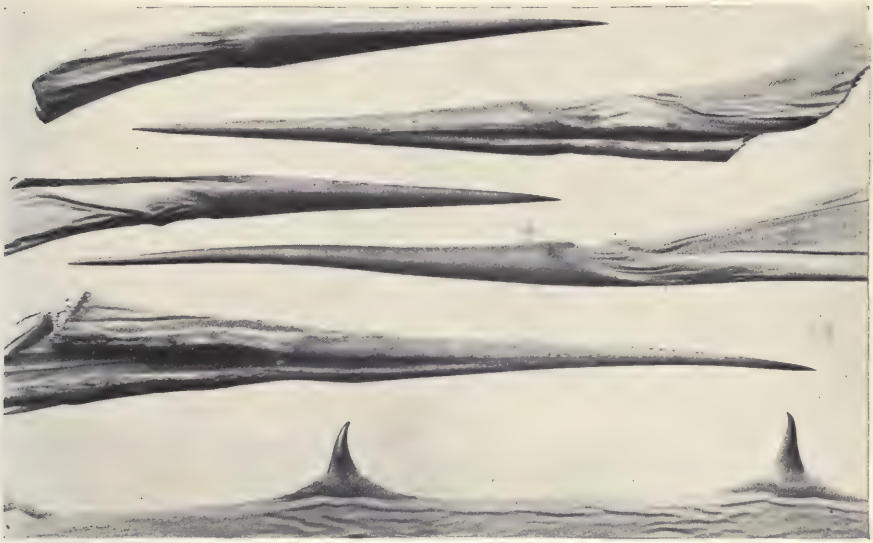
AGAVE DONNELL-SMITHII.



AGAVE DONNELL-SMITHII.

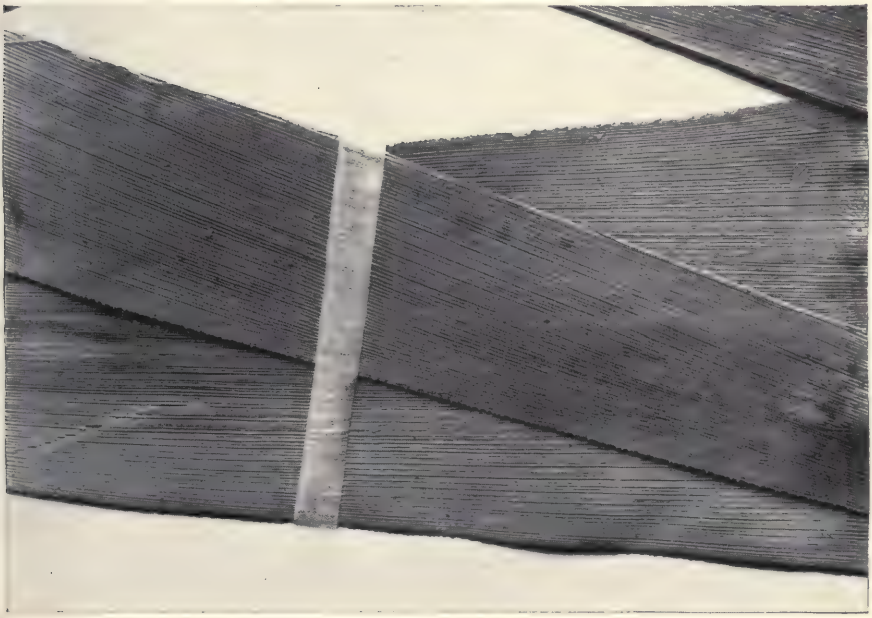
AGAVE DONNELL-SMITHII.

AGAVE TECTA.



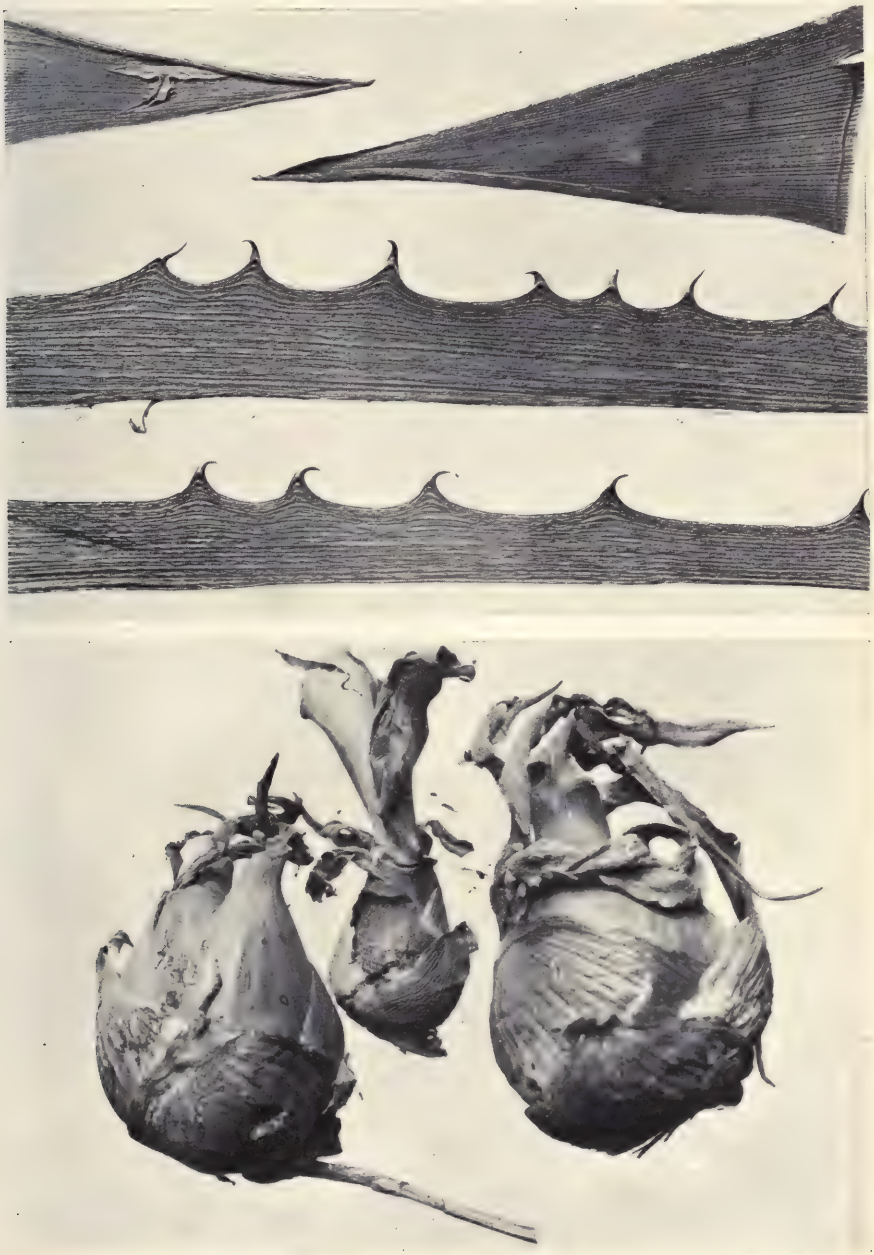
AGAVE TECTA.

FURCRAEA LONGAEVA.



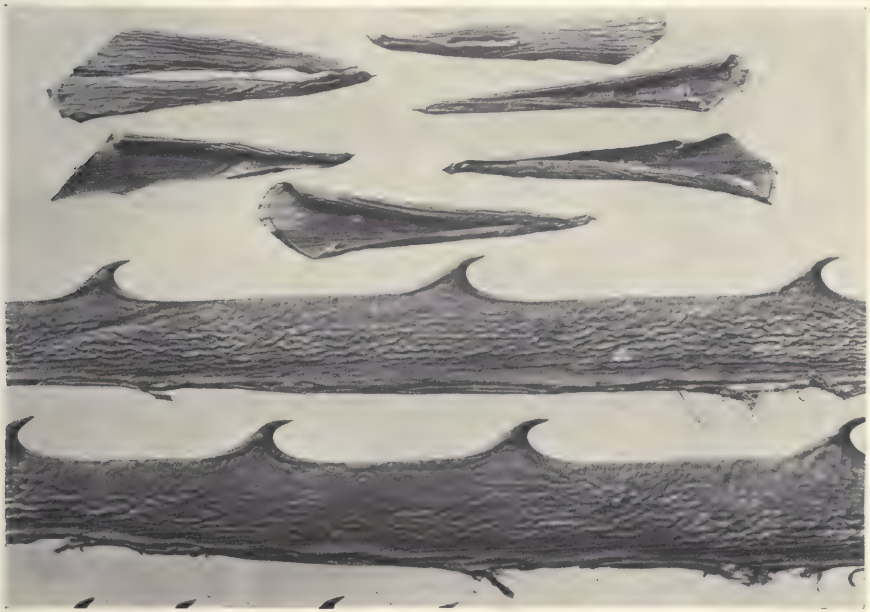
FURCRAEA QUICHEENSIS.

FURCRAEA SAMALANA.



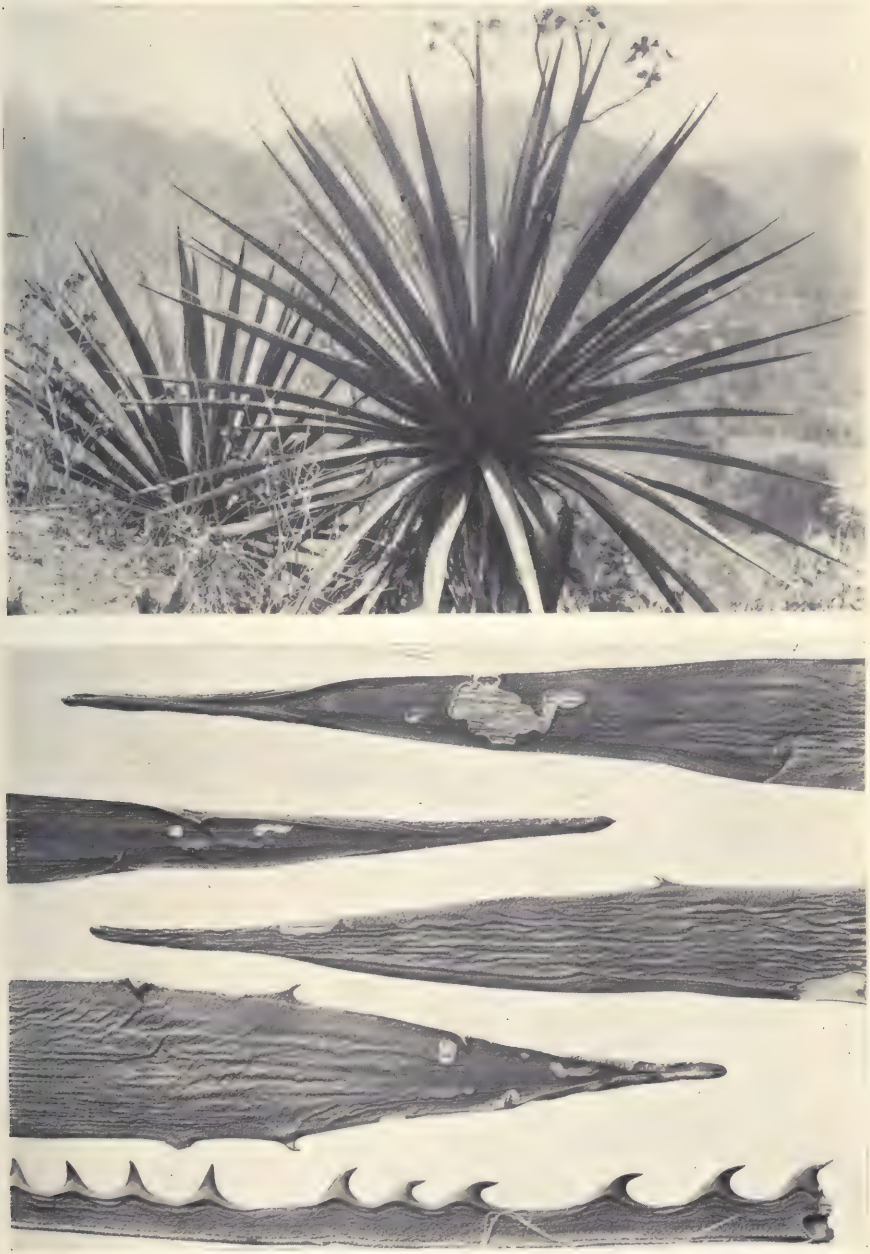
FURCRAEA SAMALANA.

FURCRAEA GUATEMALENSIS.



FURCRAEA GUATEMALENSIS.

FURCRAEA GUATEMALENSIS.



FRUCRAEA MELANODONTA.

DISTURBANCES IMPRESSED UPON THE EARTH'S MAGNETIC FIELD.*

FRANCIS E. NIPHER.

It is now thirteen years since the writer first made a long series of experiments, in which an attempt was made to reproduce, by means of explosions, the magnetic disturbances due to solar outbursts. These results were finally obtained at my summer home near Hessel, Mackinac County, Mich., during the summer of 1914.

In these experiments, half a ton of rapid burning blasting powder and 300 pounds of 40 per cent dynamite was used. The expense involved was paid by the Carnegie Institution of Washington.

The magnetic needle and its enclosing case was fully described in a former paper.[1] As in the work described in the former paper, all possible precautions were taken to make the case surrounding the needle air-tight. The damping wire dipping into coal-oil in the bottom of the glass bottle which formed the enclosing case, was only 1 cm. in length, in order to give to the needle more freedom of motion than it had in former work. The socket, provided with leveling screws into which the bottle was sealed, was securely clamped to the table. The top of the tube of metal within which the suspension fiber was hung from a torsion head, was braced by four bars of wood, inclined at an angle of 45° with the vertical. Along these bars were four heavy cords, attached to the torsion head, passing down through the table. Upon these cords were

* Presented by title to The Academy of Science of St. Louis, December 6, 1915.

[1] Variations in the Earth's Magnetic Field. Trans. Acad. of Science of St. Louis, XXII:109-110. 1913.

hung two bars of wood, at right angles to each other, each being loaded with about ten pounds of rock. This was done in order to prevent lateral vibrations of the magnetometer case. The arrangement is fairly well shown in Plate XXXVI, Fig. 1. When this view was taken two of the bars bracing the torsion-head had been removed, in order to make the details of the arrangement more clearly visible. The tent had also been removed. The magnets serving to deflect the needle into an east and west position were steel bars, four feet in length and having a cross-section 3/8x1.5 inch. These bar-magnets were enclosed in heavy rubber tubing with plugs closing the ends, and mounted in V-shaped supports within wooden boxes. The boxes were filled with dry and fine grained saw-dust, which was packed closely around the tubes enclosing the magnets. These boxes are shown at the ends of the framed structure forming the table. They were inclined at an angle of 45° with the magnetic meridian. See Fig. 1.

The compensating magnets, which served to reduce the strength of the resulting field thus formed, were of four like bars of steel. On either side of the needle were two bars in reversed position, bound together by strong cords. They were wound with adhesive rubber tape. They were separated from each other by blocks of wood having a thickness of about one cm. They were mounted on edge within the boxes. They thus acted differentially upon the needle. Single bars on either side, when placed anywhere within the available space, would reverse the needle, and give too strong a resultant field. The two boxes, each of which contained such a doublet of such compensating magnets, are shown on either side of the magnetometer in Plate XXXVI, Fig. 1. These boxes were also packed with saw-dust. The four boxes were clamped to the supporting framed structure by heavy wooden clamps. The boxes and frame were loaded with fully half a ton of rocks. An end view of the south end of the table is shown in Plate XXXVI, Fig. 2. The framed struc-

ture rested upon six posts, which were set two feet into the ground. It was held together by means of brass bolts and copper nails. It was so rigid that the impact of the body of a man against it produced no appreciable effect upon the needle.

When ignited in open air, the black powder burned rather slowly. The best results were obtained when 25 or 30 lbs. of the powder, spread uniformly over a platform of 20 square feet, was ignited directly east or west of the needle, and at a distance of a foot from the side of the tent. Boards were placed on end between the tent and the platform in order to protect the tent. The fly above the roof of the tent was moistened by a spray of water. In order to protect the magnets from any possibility of heat effects two curtains, formed of heavy blankets padded with cotton, were hung within the tent. They were so placed that an air-space of five or six inches was between the two curtains. The chair of the observer was inside of the middle of the inner curtain and between the flame and the magnetic needle. There was no explosive effect due to the burning of the powder. It required a time of about 30 seconds for 30 lbs. of powder to burn. The flame shot upward to a height of about 20 feet.

On the day when the results to be given were obtained, there was a very faint wind from the north. The sky was clear. A huge column of smoke drifted slowly upward. It practically coincided in direction with the lines of the earth's magnetic field. The effects produced were of the same order of magnitude as were often observed, due to other and unknown causes.

Plates XXXVIII and XXXIX are fairly representative of the results. The hour of the day is laid off on the horizontal axis. On the original diagram 5 cm. represent one minute of time.

On the vertical axis the reading of the position of the needle is represented, 5 cm. representing 10 scale divisions or 28.4 minutes of arc. The zero reading was at the middle point of the scale.

The strength of the field just outside of the flame, at the point occupied by the needle, was in every case increased by the flame. The commotion of the ionized molecules within the flame, decreased the permeability of the space occupied by the flame. The lines of force were deflected around this vertical column. The instant when the combustion began is represented by the arrow on the two diagrams. The effect upon the needle did not continue in any case for very much more than one minute, and it was generally somewhat less.

The explosions of dynamite in open air produced a disturbance over a very large area. In some cases as many as 22 sticks of 40 per cent dynamite were laid upon a long bar of wood, having a cross section of 1x1.5 inches. Each stick was securely bound to the bar at each end, by means of heavy binding twine. The sticks were placed end on end and the explosive cap was placed in the stick at the end of the column. The bar was mounted upon supporting posts at a height of eight ft. above the ground. No trace of the bar of wood could be found after the explosion, except the shattered ends projecting slightly beyond the column of dynamite. The marsh grass and iris which was about 2 ft. in height was closely shaved from the surface of the ground, over a distance of about 30 ft. on either side of the column. It was all deposited in a long heap directly below the line of the column. Evidently the rebound of the compression wave of air and gas from the ground, had caused an inflow which swept the grass inward and upward. No disturbance of the tent, 275 ft. distant, could be detected. A screen of boards was erected in front of the end of the table to protect the needle, but fine fibers of silk suspended within the tent showed no appreciable deflection. A window glass in our cottage, having dimensions 29x30 inches, was broken by an explosion of 25 sticks. The cottage was distant 225 ft. This does not necessarily mean that the breakage was due wholly to the explosion. A glass which replaced it also broke down a few weeks after being put in place,

although it had not been exposed to any explosion. The effect due to an explosion of 21 sticks, 200 ft. to the north of the needle, is shown in Plate XL. The arrow indicates the instant at which the explosion took place. The intensity of the field was increased at first. The change in position caused the scale reading to change by about 1 cm., the angular change being thus 28.4 minutes of arc. The highest reading was reached about one minute after the explosion. This was followed during the next minute by a decrease in H, to a value less than that just preceding the explosion. At the end of two minutes the value of H had returned to that which it had at the time of the explosion. This disturbance was attended by to and fro vibrations of the needle, which did not exist before the explosion.

On the same day, shortly after 11 a. m., when the needle had been indicating for half an hour a steady rise in the value of H, an explosion of 20 sticks was followed by a series of vibrations which continued for twelve minutes. The amplitude increased for four minutes, and the vibrations gradually ceased at the end of twelve minutes. The maximum angle of oscillation, four minutes after the explosion, was 114 minutes of arc, or forty scale divisions. The mean reading for each oscillation showed a rise in the value of H, during the first four minutes, the average reading changing by twenty scale divisions. When the vibrations ceased the reading differed from that at the time of the explosion by four scale divisions, the field being slightly weaker.

When ten sticks of dynamite were exploded there was no appreciable effect upon the needle. It did not exceed two scale divisions. When six sticks were exploded, the needle having been very quiet, the needle continued to move uniformly, and without oscillations. The field was, however, made weaker. Two minutes after the explosion, the change in reading was eight scale divisions. The field then began to increase in strength, and five minutes after the explosion it had regained the value which it

had just prior to the explosion. When three sticks were exploded the decrease in the intensity of the field was still more marked. The needle was vibrating slightly before the explosion. The amplitude increased from two or three scale divisions to twenty-five. The decrease in the intensity of the field was represented by a change in the average reading of twelve scale divisions.

It seems probable that the lines of force of the earth's field are deflected around the space which is filled with the gases liberated in the explosion, and that in the space immediately adjoining, the field is thereby made stronger, although the commotion of the air there also tends to make the field weaker. The action is a differential one. At greater distances the main effect is due to the agitation of the air, and here the field is made weaker. There must be an intermediate position where these two influences balance each other. The distance of this position will depend upon the magnitude or violence of the explosion.

In some of the preliminary work fifty sticks were mounted in the air upon a raft of logs, which was anchored in the lake to the south of the station. Its distance from the observing station was about three thousand feet. The effect of this explosion upon the needle was inappreciable. It was at that time a very surprising result. It now seems to be apparent, that an effect would have been observed if the distance had been somewhat less, or very much greater.

Another source of disturbance of the magnetic field was examined during the summer. The captains in command of the steamers plying between Mackinac Island and Les Cheneaux Islands, were directed by Mr. Geo. T. Arnold, president, to blow a long and loud blast on the fog-horn, when at a point nearest to the station. There were three opportunities on each day to make such observation. Plate XXXVII, Fig. 1, shows the location of the steamer while the horn was in operation. This view was taken from the roof of the porch in front of the

cottage. The observing station was a few rods to the left of the view here shown. The path shown in the foreground turns to the left past the station.

Observations were made upon the effect of the fog-horn during the entire summer. It soon became evident that no effect could be expected upon days when the sky was covered with clouds. The most marked effects were observed in the afternoon on clear days and when the air was quiet.

The blast of the fog-horn was sometimes followed by vibrations of the needle. Such a result is shown in Plate XLII. Such vibrations occur which are due to other causes, and it may well be that the air disturbance due to the blast of the horn is the final agency, which, superposed upon other causes, brings about rhythmical variations in the earth's field.

The usual effect upon the needle was a slow deviation in a direction indicating a decrease in the intensity of the field. In no case was the blast of the horn followed by an apparent increase in the intensity. Plate XLI gives a fair representation of the effect usually observed. Here the drop from 11.1 to 10.8 cm. in the reading during a two-minute interval indicates a change of 3x2.84 minutes of arc in the position of the needle. On two occasions the sunset disturbance followed at once. On Aug. 25 these oscillations, which represent this disturbance, began about an hour before the time when they were usually observed to begin. They are represented in Plate XLIII.

The period of oscillation was nearly uniform and the scale reading was taken at the extreme of each oscillation. If this diagram were plotted to the same scale as those which precede, these oscillations would have five times the amplitude shown in this diagram. At this time the sky was clear, and there was no appreciable wind.

The effect of dynamite explosions at a great distance from the explosions may be expected to resemble that due to the fog-horn.

These results have been repeated in the laboratory at St. Louis during the spring of 1915. Deflecting magnets which were balanced against each other on a needle which was rendered sensitive by compensating magnets were used, as in former experiments. One of the deflecting magnets was much feebler than the other, so that it was nearer to the needle than the other. The air around the smaller magnet was electrified. A musical note from an organ pipe produced effects which were superposed upon other disturbances of similar magnitude. The effect of the musical note was appreciable, although at times the other disturbances interfered with the result. The blast of air from a compression tank, by means of which the organ pipe was operated, produced more marked results. The blast of air from a rubber tube was directed through the space between the smaller deflecting magnet and the metal shield around the needle.

During the summer of 1914 an attempt was made to examine the magnetic field around a column of exploding dynamite. The effect sought was an Ampère effect due to a special form of Rowland's convection current. A half stick of dynamite was crumbled into fine powder, and packed into the angle of a wooden trough made from bars of wood. The explosive cap was placed at the end of the column. The trough was placed in the position shown in Plate XXXVII, Fig. 2. It was in line with the needle and eight inches above the level of the needle. The inner end of the trough was about ten inches from the tent and about 7 feet from the needle. Great difficulty was found in making the entire column explode. In two cases a complete explosion of the column, having a length of 15 ft. occurred. In these cases the wood of which the trough was made was of very inferior quality and the entire trough was shattered into small splinters which were scattered over a distance of 30 ft. In these two cases the cap was placed at opposite ends of the column. The needle was deflected in opposite directions in the two cases. The deflection was such as would be caused by

negative electrons moving in the same direction as the explosion. In other cases the explosion was not complete. In many cases not more than six or eight inches of the column would explode, and the results were conflicting. In the two cases above referred to the deflection was in one case 51 minutes of arc and in the other 54.

It was found that vibrations of the trough, or breaking of the bars into long and large fragments which were not detached from it resulted in disrupting the column of dynamite. It was found that large rocks hung from the trough had a tendency to keep it in stable position and prevented the vibrations.

It has since been found that when the dynamite is slowly poured into a long rubber tube, which is gently tapped in order to make the column continuous, the explosion can be made complete. The tube must be hung in a vertical position while being filled. This work on the convection current is in an unfinished condition.

EXPLANATION OF ILLUSTRATION.

Plate XXXVI; Figs. 1 and 2. Table for magnetic observations.
Plate XXXVII; Fig. 1. Steamer. Blast of Fog-horn.
Plate XXXVII; Fig. 2. Wooden trough containing column of dynamite.
Plate XXXVIII. Magnetic effect of a flame.
Plate XXXIX. Magnetic effect of a flame.
Plate XL. Magnetic effect of an explosion.
Plate XLI. Magnetic effect of sound-waves.
Plate XLII. Magnetic effect of sound-waves.
Plate XLIII. Magnetic effect of sound-waves.

Issued July 28, 1916.

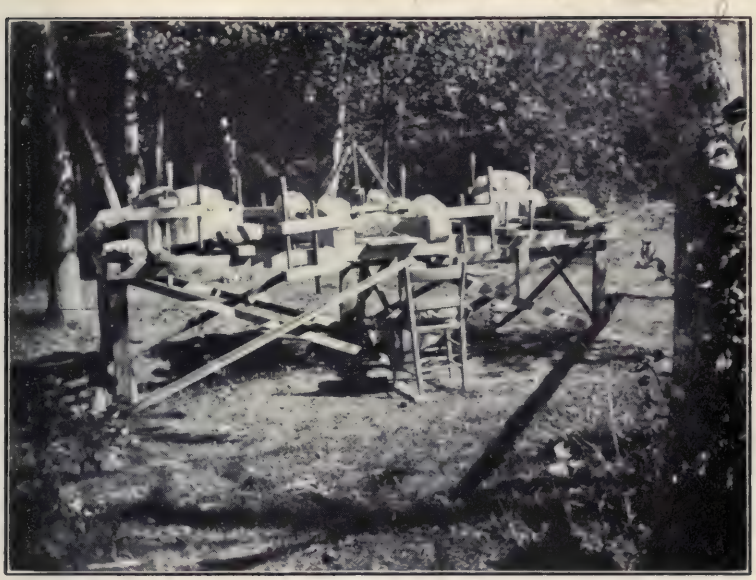


FIG. 1.

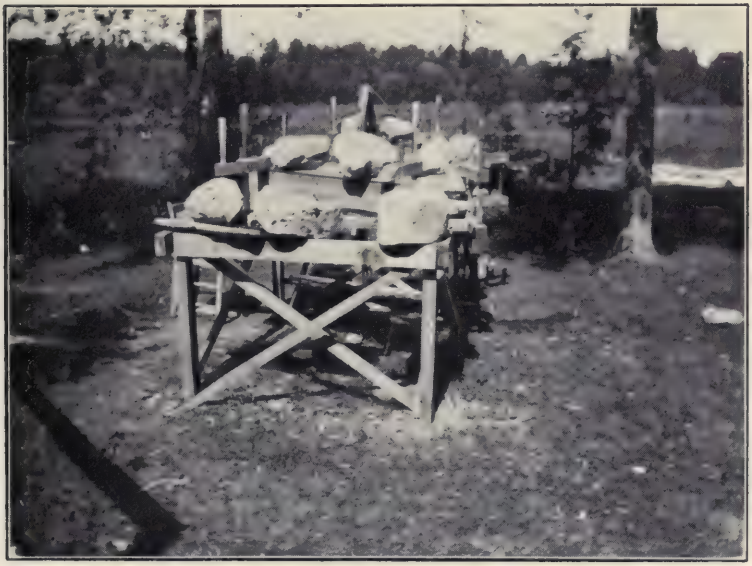
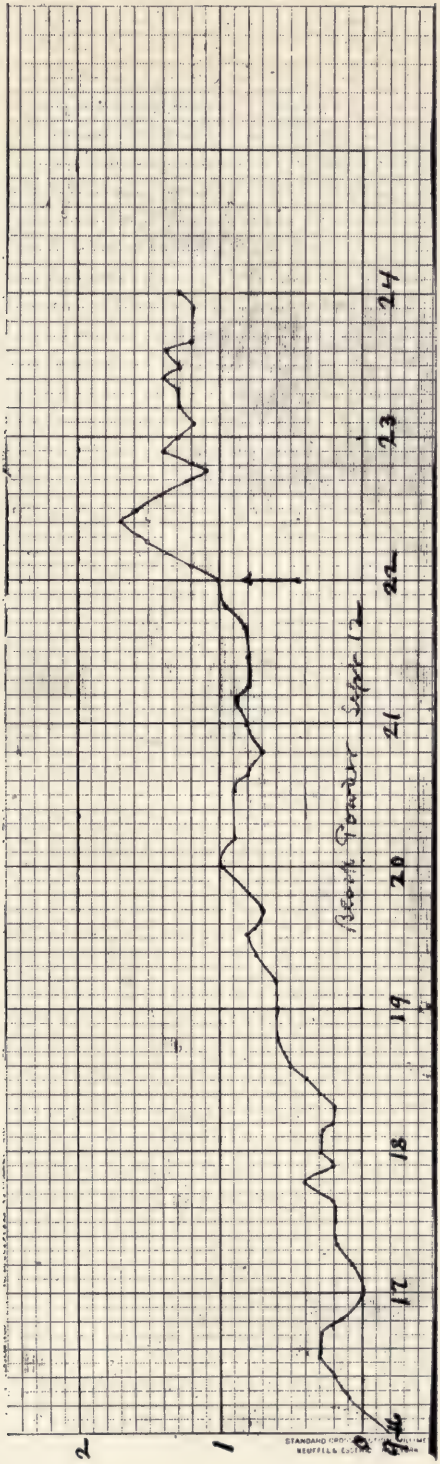


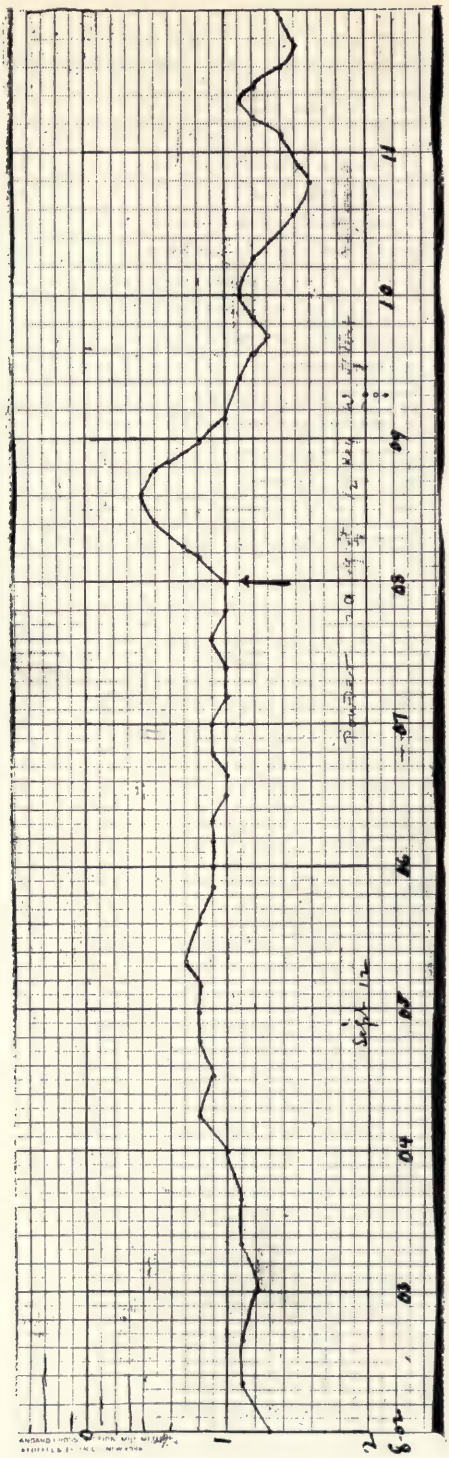
FIG. 2.

FIG. 1.

FIG. 2.



MAGNETIC EFFECT OF A FLAME.



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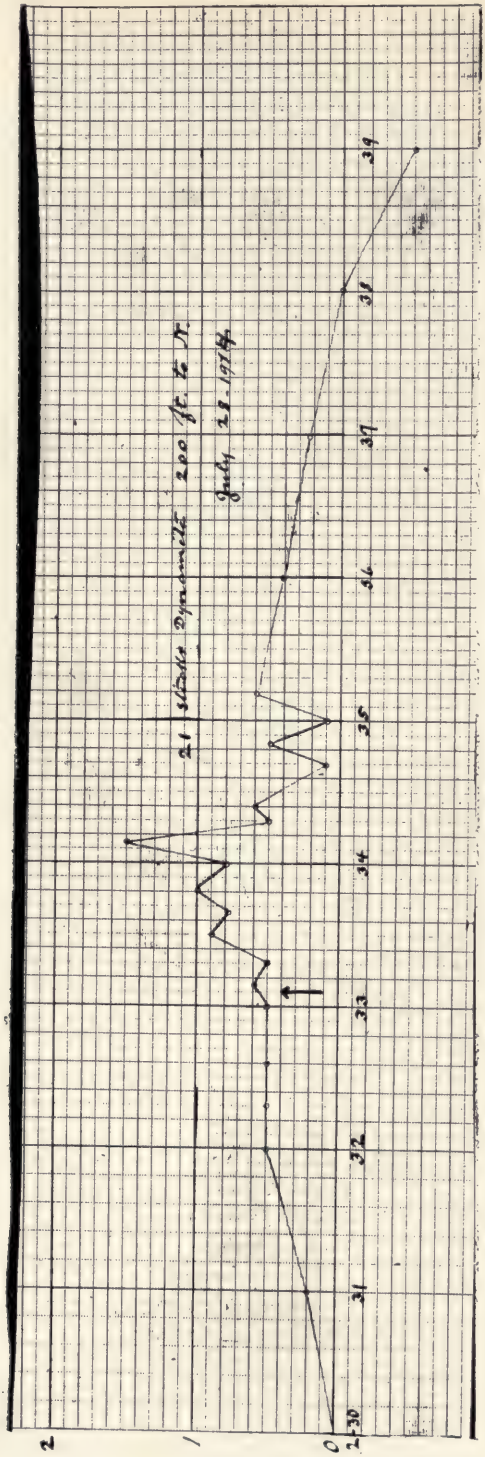
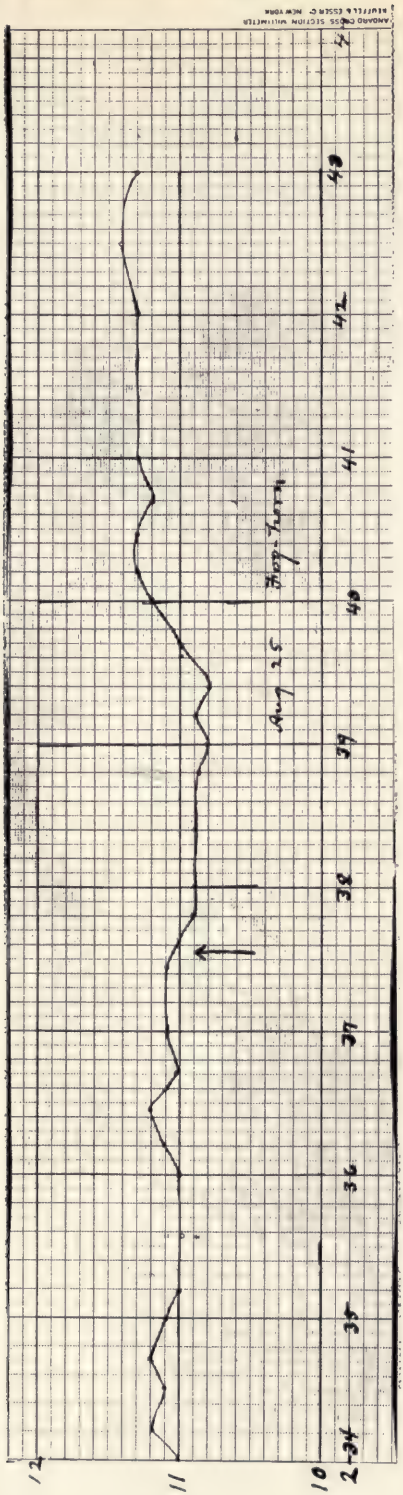
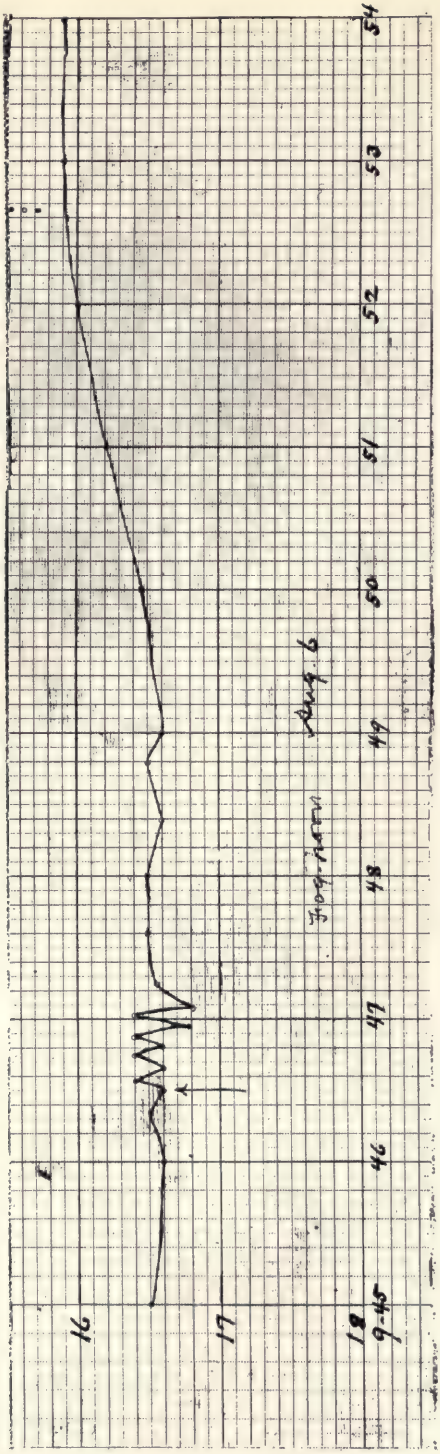


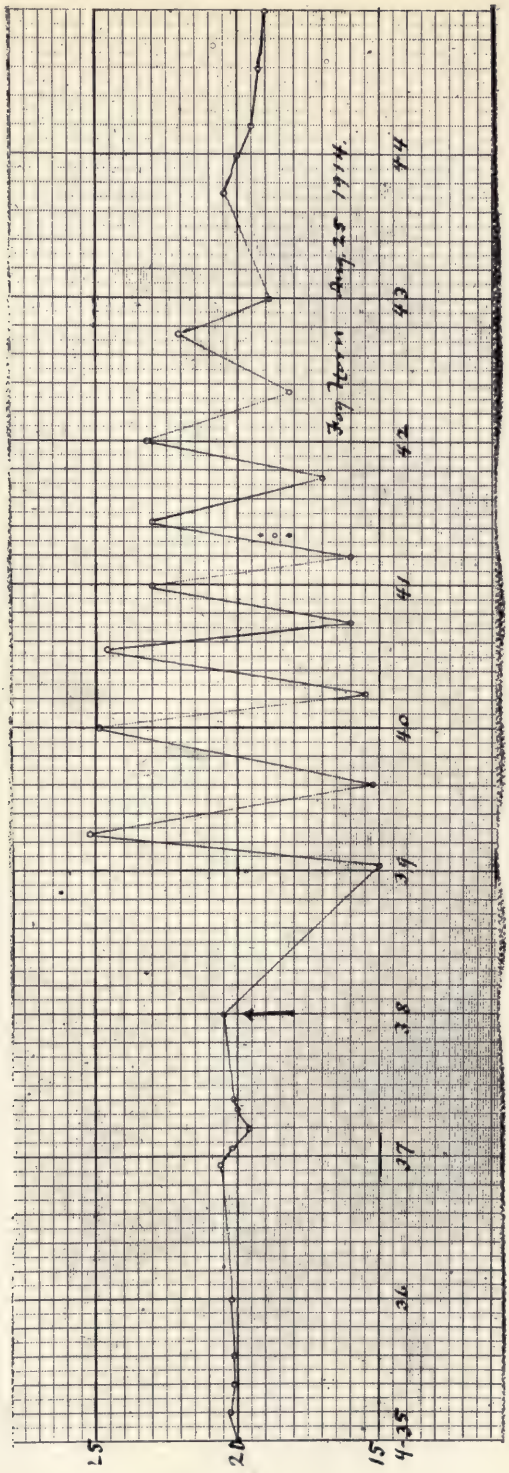
MAGNETIC EFFECT OF AN EXPLOSION.



MAGNETIC EFFECT OF SOUND WAVES.



MAGNETIC EFFECT OF SOUND WAVES.



MAGNETIC EFFECT OF SOUND WAVES.

GRAVITATION AND ELECTRICAL ACTION.*

FRANCIS E. NIPHER.

In former publications the present writer has suggested an intimate relation between gravitation and electrical action.[1]

There can be no doubt of the truth of the statement, that the attraction between any two masses of matter, depends not only upon the amount of matter in the two masses, and their distance from each other, but also upon their electrical condition.

Assume that two spheres, having radii R_1 and R_2, composed of metal having a density ρ, and distant from each other r, have electrical charges Q_1 and Q_2, the spheres having a common potential V. Their attraction for each other will be:

$$A = K\frac{m_1 m_2}{r^2} - \frac{Q_1 Q_2}{r^2}$$

$$= K\frac{16}{9}\ \frac{\pi^2 R^3{}_1 R^3{}_2\ \rho^2}{r^2} - \frac{R_1 R_2}{r^2}\ V^2$$

$$= K\frac{16}{9}\ \frac{\pi^2 R^3{}_1 R^3{}_2\ \rho^2}{r^2} - \left(\frac{9 m_1 m_2}{16\ \pi^2 \rho^2}\right)^{1/3}\ \frac{V^2}{r^2} \quad (1)$$

Here K is the Newton constant of gravitation as it would be determined if electrical action were eliminated, or if V were zero absolute. The absolute zero in V

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[1] Proc. Am. Phil. Soc. Philadelphia 52: 283—6.
Science Sept. 1, 1911: 282-3.
Experimental Studies in Electricity and Magnetism. 19-24.

would be the common potential of the two bodies, under the conditions assumed in Eq. (1), when their attraction for each other is a maximum.

The gravitation constant has been determined by methods, which it was assumed made it unnecessary to consider the electrical condition of the two bodies. Nevertheless the results have been very unsatisfactory. In his presidential address before the American Mathematical Society in December, 1899, R. S. Woodward referred to this constant as being one of the constants of the solar system whose determination was in a most unsatisfactory condition, as regards precision.[2]

If the masses are capable of acting upon each other electrically, and the final term in Eq. (1) is omitted, that equation might be written.

$$A = K\left(1 - \frac{x}{100}\right)\frac{16}{9}\ \frac{\pi^2 R^3_1 R^3_2 \rho^2}{r^2} \qquad (2)$$

In this equation an error of x per cent. in the value of K would result. By (1) and (2).

$$V = \frac{4}{3}\pi R_1 R_2 \rho\ \frac{\sqrt{K x}}{10}$$

If V is measured in volts,

$$V = 40\pi R_1 R_2 \rho \sqrt{Kx} \qquad (3)$$

For purposes of illustration assume that $K = 6.6576 \times 10^{-8}$ and that $R_1 = 10_1$, $R_2 = 1$ and $\rho = 11.35$; then

$$V = 3.68\sqrt{x}$$

If the common potential of the two spheres differs from absolute zero by 3.68 volts, the value of K would be in error by one per cent of the above value, which is that of Boys, unless adequate means are taken to eliminate the effects represented by the final term of Eq. (1).

If V were $\pm$ 8.23 volts an error of five per cent would result. If V were $\pm$ 36.8 volts, the two spheres would

[2] Bulletin Am. Math. Soc. II 6:153.

have no attraction for each other, although both would be attracted by the earth, even if it had the same potential. The attraction of the earth for a gram of lead would then be by (1)

$$A = 981 - 0.000,000,000,006.$$

The acceleration of a falling body would be practically unchanged, and would not depend upon the density of the matter of which it is composed, as it would apparently be under the conditions assumed in Eq. (1).

Raindrops falling through an overcharged[3] thundercloud would repel each other. After the diverging branches of a flash of lightning have penetrated the cloud a new condition has arisen. Overcharged drops of water along the lines of the intricate system of branches of the discharge, have delivered their overcharge to the cloud at the other end of the long flash. These drops are intimately commingled with drops which are outside of the drainage lines. The value of V for these two groups of drops now have opposite signs. The final term in equation (1) then becomes positive, as applied to these groups, and it is much greater than the gravitation term. These drops coalesce as they fall to earth and a brief dash of unusually large drops of rain follows.[4]

In former papers above referred to, an experimental study of explosive effects due to a discharge from a large condenser through a small lead wire was discussed. The wire was sealed within a glass tube filled with coal oil. This work has been continued in a modified form. Four quarter ampère fuse-wires of lead were placed in multiple across a gap, five centimeters in length in a line leading from either terminal of an influence machine to a

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[3] The word overcharged, or super-charged, was in common use more than a century ago, when the one-fluid theory was in general favor.

[4] See Nipher. A Flash of Lightning. Popular Science Monthly. Jan., 1912: 76.

Nipher. Experimental Studies in Electricity and Magnetism. Pp. 16-17.

water-pipe system. The other terminal was grounded on a gas pipe. The lead wires were clamped between the leaves of two small brass door-hinges, one leaf of each hinge being soldered to one of the ends of the rods at the gap. Between the gap in which the leaves were mounted and the ground was placed a large battery jar filled with four litres of a solution of common salt. The wire was parted at this point, and the ends were immersed in this solution which thus formed part of the ground circuit. One of the wires penetrated the liquid to a depth of about half a cm. Between the gap in which the wires were mounted and the machine was a spark gap, between knobs of equal radius. The condenser consisted of forty large sheets of glass (36x36 inches) having upon them 2x40 square feet of tinfoil. The machine was driven by a single-phase electric motor. Below the lead wires a sheet of white paper was laid upon a plate of glass.

It was found that there was a marked difference between the effect of the positive and the negative discharges upon the lead wire. The resistance of the gap in the salt solution could be so adjusted, that the negative discharge, or the compression wave, would cause the lead wire to fuse and drop in hot globules upon the paper below. The effect upon the paper is shown in Plate XLIV, Fig. 1.

With the same adjustment, the positive discharge causes the lead wires to rise in a cloud of dust. If the paper were placed 3 cm. below the wires, it would usually be practically unaffected when the positive discharge was used. In a few cases, as in Fig. 2, it was slightly discolored by the lead fumes.

Of course the discharge could be made greater, so that either discharge would cause the lead to be dissipated in a cloud. It could be made less, so that fused metal would fall upon the paper when the positive terminal was connected with the ground line containing the wire. In all cases the cloud effect was the more marked in case of the

positive discharge, and the fused metal falling upon the paper was less marked.

In case of the positive discharge there is of course a heat effect. Part of the result is due to this cause. But if we are to consider the positive terminal as an exhaust terminal, into which the negative electrons are suddenly drained and thence into the positive sheets of the condenser, we may explain the result as an explosive condition which is suddenly impressed upon the lead. When deprived of negative corpuscles, each atom repels every other. The negative term in equation (1) has become very much greater than the positive, when applied to inter-atomic attraction under these conditions.

The negative discharge, which is to be regarded as a compression wave could not give a super-charge to atoms within the wire, causing them to repel each other. The super-charge is on the outside of the wire. The one-fluid theory seems to furnish a more rational explanation of these phenomena than the two-fluid theory, as is the case in the phenomena of the Crookes tube.

Some work has been done in the examination of the effect of the electrification of air within a glass vessel, upon the pressure of the air on the walls of the containing vessel. A large three-necked Wolff's bottle was used, the three openings being provided with rubber stoppers which had been treated with vacuum wax. The bottle had a volume of 9.6 litres. Through the central stopper was passed a copper wire to which were attached 150 pins. The outer part of this wire was in contact with a metal conductor, having a length of about ten feet, which extended to a point near the terminals of the influence machine. This conductor was symmetrically placed with respect to the terminals. It terminated in a disk of copper having 150 pins whose heads were soldered to one of its faces. This many pointed terminal could be placed directly in front of either of the large knobs of the machine, at a distance of 10 cm., the other knob, or terminal, being grounded.

A U-shaped water gauge was mounted in another stopper of the flask. In the third stopper of the flask a tube with a bulb containing calcium chloride was mounted, this tube being provided with means for connecting the confined air with the outer air. The condensers were wholly removed from the machine. The glass bottle was placed upon a sheet of heavy plate glass.

When the discharge-knobs of the machine were near enough together so that the brush discharge between them was accompanied by faint disruptive effects, the pressure within the flask could be increased by about two grams-weight per sq. cm., the effect of the negative electrification being somewhat greater than that of the positive. When the knobs were far enough apart to prevent disruptive discharges, no luminous effects being observed within the flask, the change in pressure due to either terminal was reduced to between one and two mm. as shown by the water gauge. After the pressure due to electrification of the air had reached a final limit, a transfer of the many pointed collector to the front of the other terminal, would result for a time in a slow decrease in pressure, and then in a slow increase to the former limit. The decrease in pressure did not begin until the discharge from the other terminal had begun. Heat effects had been practically eliminated.

If the gas contains moisture a permanent decrease in pressure at once results, due to condensation of vapor upon the sides of the vessel.

These results seem to indicate that there is an electrical condition of the gas, for which the Boyle-Gay-Lussac constant is a minimum. When this condition is reached, the second term of equation (1) is zero, as applied to molecules of gas.

An attempt has been made to determine whether or not the value of the gravitation term of Eq. (1) can be affected by electrical action, when the effect represented by the final term is eliminated. The apparatus used was

a modified form of that used by Cavendish. The suspended masses consisted of two lead tubes, each being about 15 cm. in length, each having a mass of 50 grams. They were mounted around the ends of a brass tube 91 cm. in length, and having a mass of 30 grams. This tube was suspended upon two loosely twisted threads of silk fibers, 180 cm. in length, whose distance apart was approximately 0.4 cm. The twist was removed from these threads by hanging upon each a mass of 65 grams. This formed a very sensitive bifilar suspension. The suspended masses were wholly surrounded by a metal shield of rectangular form 10x12.5 cm. in cross section. The suspension fibers were enclosed in a metal tube, having a torsion head at the top, thus providing means for properly adjusting the position of the brass tube. The ends of the rectangular shield were provided with metal caps, fitting closely into its ends. They entered the shield a distance of 2.5 cm. An opening at the middle of the shield, in front of a mirror mounted upon the suspension wire, served for observation of position by means of a telescope and scale. This opening was covered by a sheet of glass which was sealed to the shield by means of sealing-wax. The window was covered with a metal wire screen having about 5 wires per running cm. The mirror was observed through this wire screen, the telescope being focused upon the scale at the telescope. A change of one scale division represented a change of 2.36 minutes of arc in the position of the suspended tube. The suspended masses and the brass tube on which they were mounted were surrounded by sheets of asbestos paper, which fitted into the caps at the ends of the shield, and fitted loosely the interior of the shield. These two linings formed extensions of the end caps and were intended to prevent a convection of the air within the shield.

The large masses each consisted of two fifty-pound weights placed one upon the other and mounted upon heavy columns of rubber. They were separated from the metal shield by a space of about 2 cm. In this space was

placed a sheet of glass and three layers of asbestos paper.

The shield was mounted upon a heavy piece of timber and rested directly upon a sheet of glass. It was also wrapped with asbestos paper. The long suspension tube was held in stable position by three heavy silk cords attached to surrounding cases, and loaded with a series of distributed masses, about 25 in number, and having a mass varying from 50 to 100 grams each. The metal shield was loaded with two ten-pound masses of iron and its sides were clamped with wooden clamps in order to quiet any vibrations in the shield. The large iron masses and the metal shield were connected with each other by large copper wires, leading to a spark-knob mounted upon the table. Another spark-knob, mounted on an independent support, was provided with a discharge terminal, consisting of 150 pin-points, the heads of which were soldered to a copper disc. The entire apparatus was mounted upon a massive table. The floor of the room was of reinforced concrete. The discharge terminal was connected with the influence machine in an adjoining room, by means of brass rods hung upon silk cords. The machine was operated by a synchronous electric motor. The discharge knobs at the machine were separated so that no disruptive discharges were possible. One terminal of the machine was grounded. There were no condensers on the machine terminals.

The time interval of a to and fro vibration of the suspended masses was 485 seconds. When at rest there appeared to be no disturbance of any kind. The reading would somtimes remain constant for hours. At other times the reading slowly changed. It often varied throughout a day through 20 scale divisions. It was found that the large masses appeared to attract the suspended masses with a varying force, even when the former were hung from the ceiling above. Sometimes they appeared to repel the suspended masses. These varying effects were finally traced to very moderate changes

in the temperature of the room. It was found that the flame of a wax candle, placed fourteen inches from either of the suspended masses, exerted a marked apparent attraction for them. When a sheet of glass and two sheets of asbestos paper were placed between the candle flame and the metal shield, it being provided with a wrapping of asbestos paper in addition to the inside lining of the same material, an apparent attraction resulted. A change of 20 scale divisions would then result in two minutes. This result was obtained with either of the suspended masses, when the other was protected by the two 50-lb. masses and other means before mentioned. Fluctuations in the flame of the candle due to the condition of the wick produced observable effects. When the outer wall of the screen was rising in temperature more rapidly on one side of the suspended mass than on the opposite side, this mass moved towards the warmer side. This was apparently due to the convection effect of air within the lining of the metal screen.

The suspended rod bearing the small masses was below the central axis of the enclosing shield. If one side of the shield was warmer than the opposite side the suspended rod would be in a slowly drifting current of air, which would urge it towards the warmer side of the screen, or away from the colder side. The temperature of the large masses lagged behind that of the screen in the small daily changes in the temperature of the room.

The effect of a noiseless discharge from the pin-point terminal into the air around the knob connected with the screen and the large masses, was to produce an apparent decrease in the attraction of the large masses for the suspended masses. This result was obtained when no trace of disruptive discharge could be detected. After the extreme displacement thus produced had been reached, the distance between the pin-point terminal, and the knob connected with the shield and the large masses, was increased from 15 to about 90 cm., the charged bodies being then grounded. This was done by means of a

fine wire attached to an insulated rod, which could be laid upon the floor of the room, or lifted into contact with a rod, one end of which rested upon one of the large masses. The pin-point terminal was meantime made to face another grounded conductor. The suspended masses then swayed to the other extreme position during the next four minutes. By a repetition of this operation, the arc of vibration could be increased from one or two scale divisions to twenty-six in an interval of an hour. The average of the extreme readings of consecutive vibrations, usually showed slow progressive changes of two to five scale divisions per hour. Sometimes the average reading showed a decrease and sometimes an increase. The results were of the same order of magnitude whether the masses were connected with the negative or with the positive terminal of the machine, although most of this work has been done by the positive "discharge."

It was suspected that this result might be due to a slight rise in the temperature of the walls of the metal shield. If this were the case it must be assumed that while the gap at the pin-point terminals was least, the rise in temperature was least in that part of the sides of the metal screen facing the large external masses.

In order to examine this influence, a delicate air thermometer was extemporized. The bulb consisted of an oil-can having a capacity of 4.5 litres (one gallon). Connected by a rubber hose with the nozzle of the can was a horizontal tube of glass, having a length of 75 cm. and an internal diameter of 0.76 mm. Within this tube was a short column of water, serving as an index. The entire device was insulated upon glass supports. A candle flame 20 inches distant from the can caused the index to move over a distance of 2 cm. in 15 minutes. When the candle flame was removed and the can was electrified and in electrical contact with the large masses and shield, no change in the position of the index column could be detected, when observed by means of a telescope.

The large masses were then wholly enclosed in two metal boxes, from which the masses were insulated. The masses rested upon rubber blocks placed upon the bottom of the boxes, and each box was mounted upon rubber blocks which rested upon plates of glass. The masses were in the same position as in the work above described. The boxes were separated from the shield, enclosing the suspended masses, by the plates of glass and the asbestos paper.

The two metal boxes and the metal shield were then electrified precisely as has been done before. It was then found impossible to increase the arc of vibration of the suspended masses, although the operation was continued for several hours. If the former results had been due to heat effects, they should have produced the same results in this case. The large masses were removed from the enclosing boxes. The empty boxes and screen were then electrified as before.

No change in the amplitude of vibration could be produced.

These results seem to indicate clearly that gravitational attraction between masses of matter depends upon their electrical potential due to electrical charges upon them. To assume a special case, such as exists when the gravitation constant is being determined, Newton's law holds only when the common potential of the two bodies is such that their gravitational attraction for each other is a maximum. If the two masses are not separated by a metal shield and their common potential is that of the earth, these masses will repel each other by a force represented by the final term in Eq. (1) and the value of K will also be diminished, if the above conclusions are correct. If the two masses are separated by a metal shield, this final term will be eliminated, but the value of K will be diminished and may seem to be variable, if there are local variations in the potential of the earth. By adjusting the potential of the attracting masses by well known means we may hope that the real value of K and the

absolute potential of the earth may be determined. This is a problem for the future to solve.

In the work discussed in this paper an effort has been made to eliminate heat effects from all sources. It may be that alternating discharges from a high potential transformer would produce more marked effects than have been observed by the methods above described. The surging of negative electrons within the large attracting masses would be greatly increased. This would also involve heat disturbances, the effect of which would cast a doubt upon the results. Under the conditions in which this work was done the amplitude of vibration of the suspended masses sometimes changed in a way that seemed to discredit the above conclusions. It was finally found that variations in the illumination of clouds in the northern sky produced marked effects upon the position of the suspended masses. The apparatus was fifteen feet distant from five large windows in the north wall of the room. The variation in radiation from such clouds was occasionally followed by a marked change in the amplitude of consecutive vibrations. After such disturbances and others not here referred to had been eliminated, there still remained distinct evidence that the value of the gravitation constant as it has been determined, is dependent upon the electrical potential of the attracting masses, when the effect represented by the final term in equation (1) is wholly eliminated by a metal screen.

Plans are now being prepared which will, it is hoped, result in a determination of the change which can be produced in the value of the gravitation constant, by electrification of the larger masses.

The writer desires to acknowledge the financial aid granted to him by the Carnegie Institution of Washington.

EXPLANATION OF ILLUSTRATIONS.

Plate XLIV; Fig. 1. Fusion of lead wire by negative discharge.
Plate XLIV; Fig. 2. Explosion effects due to positive "discharge."

Issued July 28, 1916.

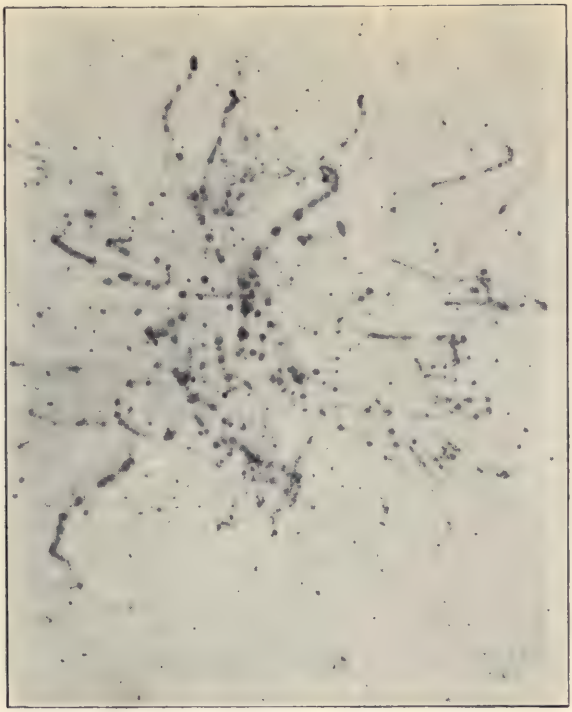


Fig. 1.

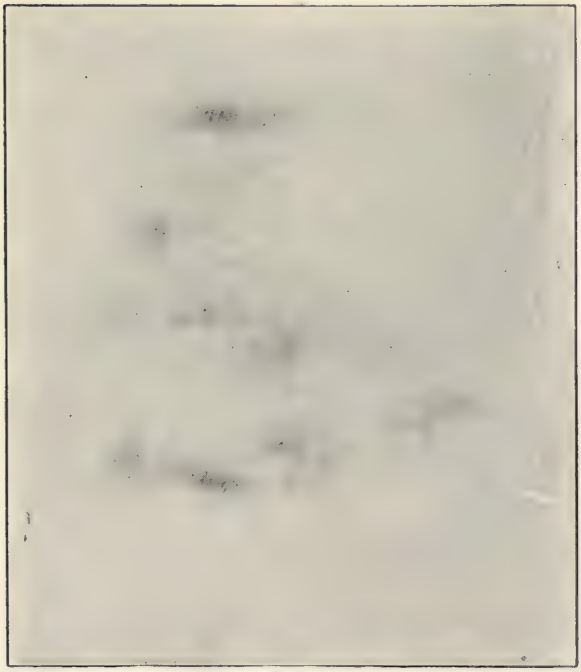


Fig. 2.

FUSION AND EXPLOSION EFFECTS ON LEAD WIRE.

GRAVITATIONAL REPULSION.*

Francis E. Nipher.

In a former paper published by the Academy on July 28, 1916, the following passage may be found:[1]

"These results seem to indicate clearly that gravitational attraction between masses of matter depends upon their electrical potential due to electrical charges upon them."

Every working day of the following college year has been devoted to testing the validity of the above statement. No results in conflict with it have been obtained. Not only has gravitational attraction been diminished by electrification of the attracting bodies when direct electrical action has been wholly cut off by a metal shield, but it has been made negative. It has been converted into a repulsion. This result has been obtained many times throughout the year. On one occasion during the latter part of the year, this repulsion was made somewhat more than twice as great as normal attraction.

The large masses used in this work were spheres of lead ten inches in diameter. They were mounted upon blocks of dry wood, which were mounted upon caster-wheels provided with roller bearings. The wheels rested upon heavy sheets of hard rubber. The suspended masses were two spheres of lead, having a diameter of one inch, mounted upon the ends of a brass tube. Their distance apart, from center to center was 91.5 cm. They were hung upon two untwisted threads of silk fibers, forming a bifilar suspension. The length of the threads was 179 cm., and the distance between them was about 3.4 millimeters. Near the top of the long metal cylinder

* Presented by title to The Academy of Science of St. Louis, Oct. 22, 1917.

[1] Trans. Acad. of Sci. of St. Louis, XXIII, No. 4, p. 173.

enclosing these suspension fibers, was a lateral brace formed of two bars of hard rubber, about 30 cm. in length. The ends of these bars formed a right angle against which the vertical suspension cylinder was pulled. These rubber bars formed the ends of two long bars of wood attached to the tops of instrument cases along adjoining sides of the room. The bars were also supported by a framed structure. Silk cords attached to the cases ran along the two bars and were tied to the suspension cylinder. Weights distributed along these cords served to hold the cylinder against the ends of the rubber bars. Vibrations of the suspension cylinder were thus wholly eliminated. The torsion head forming the top of the cylinder was provided with a rod which extended radially outward to a distance of about 20 cm. By this means the torsion head could be turned in order to put the suspended masses into vibration. The top of the suspension cylinder had a similar rod clamped to it having an upward projecting stop, by means of which the torsion head could be returned to the original position. Change in the temperature of the air within the shield resulting in a change in volume was provided for by the outflow or inflow around the torsion head.

The enclosing case was of the general form used by Cavendish. In the early part of the year it was formed wholly of metal. It rested upon insulating blocks of rubber, which were mounted upon two long pieces of timber having a cross section of 4x4 inches. These timbers rested upon a massive table, which was on a floor of reinforced concrete within a building having granite walls. At the central part of the metal shield the dimensions were 5x5 inches. A narrow slit on one side covered by a small plate of glass sealed to the shield, served for observing the movement of the suspended masses by means of a telescope and scale. At the outer ends of the shield, the lateral dimension was about 15 inches. This form was chosen in order that the suspended masses and the brass tube upon which they were mounted could be in-

closed by a cylinder of copper wire gauze, between which and the outer screen was very loosely packed cotton fiber. A thin layer of cotton was placed at the ends of the screen, being also held in place by wire netting. This was designed to diminish convection effects.

The body of the observer was wholly below the level of the table. Radiation of heat from the head to the screen was cut off by sheets of heavy cardboard.

The two rooms used for this work were wholly disconnected from the heating system of the building. During the day the temperature of the large masses was usually slightly lower than that of the shield around the suspended masses. This temperature difference never exceeded 1°.5 C.

The large masses were placed at the ends of the screen or shield in line with the rod upon which the small masses were mounted, in order to determine their effect upon the time of vibration of this bifilar pendulum. The large masses and screen were in direct metallic connection, and the air around them was electrified by a discharge from pin-points. A disc armed with 150 pins was placed with the pin-points 4 cm. from each of the large masses. A noiseless discharge was delivered from the points of the pins.

Let T represent the time of vibration when the masses were away.

Let T_1 represent the time of vibration when the masses are in place.

Let T_2 = the time when the masses and screen are electrified.

Then

$$T = 2\pi \sqrt{\frac{I}{m\, g\, \frac{d^2}{l}}} \qquad (1)$$

Here m is the suspended mass, $2d$ the distance between the two silk fibers on which it is suspended, and l their length. I is the moment of inertia.

When the large masses are in place

$$T_1 = 2\pi \sqrt{\frac{I}{D + 2\,b\,G\,\frac{M\,m'}{r_2}}} \qquad (2)$$

Here D is the directive constant of Eq. (1), b the distance between the centers of the two suspended masses m', and r the distance between the suspended masses and the large masses M. The equivalent of the brass rod is included in m'.

When the large masses are electrified, if the time of vibration is increased to T_2 and we assume that this is due to a decrease in the value of the gravitation constant G, then

$$T_2 = 2\pi \sqrt{\frac{I}{D + 2\,b\,G\left(1 - \frac{n}{100}\right)\frac{M\,m'}{r^2}}} \qquad (3)$$

From these equations

$$\frac{n}{100} = \frac{T_2^2 - T_1^2}{T^2 - T_1^2} \times \frac{T^2}{T_2^2} \qquad (4)$$

The time of vibration was determined by means of a chronograph belonging to the department of astronomy of the University. The key was snapped when the mean reading passed the cross-hair of the telescope. The mean reading was obtained from the reading of the four extremes of the two complete vibrations which immediately preceded. The values here given are the mean of six complete to and fro vibrations and the probable error does not in any case exceed 0.25 sec.

Observations March 10, 1916.

$T = 623.0$ sec.
$T_1 = 614.5$ sec.
$T_2 = 625.0$ sec.

By Eq. 4, $\frac{n}{100} = 1.23$

When T was determined the temperature of the air in the room was 15°.5 C $= t_a$

The temperature of the screen was $t_s =$ 15°.2 C.

When T_1 was determined,

$$t_a = 17°.4 \text{ C}$$
$$t_s = 17°.4 \text{ C}$$

The temperature of the two large masses was 16°.4 and 16°.6.

These values were determined by means of four thermometers reading to tenths of a degree. The bulbs were placed in contact with the masses, and covered with a layer of cotton batting.

When the readings for T_2 were finished

$$t_a = 18°.0 \text{ C}$$
$$t_s = 17°.9 \text{ C}$$

The temperature of the large masses was 17°.7 and 17°.8.

On a former occasion, when the bifilar suspension was different, it was found that placing metal vessels containing a litre of water having a temperature of 28° C. at the beginning of the experiment, and 24° at the close, in the positions occupied by the large masses, the temperature of the air and shield being 13°.8, the value of T was increased from 644.2 sec. to 652.5. The warm vessels were in contact with the shield.

When the metal vessels contained water and ice, the temperature of the air and shield being 12°.0, the value of T was decreased by 25 seconds.

These results seem to indicate clearly that convection of the air within the shield had no material effect upon the values of the quantities used in computing the value of n in Eq. 4.

It apparently follows that the value of the gravitation constant was made negative by the process described. Attraction was converted into a repulsion. The influence machine was unusually active by reason of fresh drying

material in the case in which it was enclosed. On other days the value of G was decreased by 16, 23, 27, 69, 77, 134 and 184 per cent of its initial value. It is not claimed that these are results of any high degree of precision. During the first week while the bifilar method above described was being tested, the time of vibration during a period of two hours was found to be very constant. For example, in the first determination made on October 23, the mean position of the suspended masses was determined from readings of the extremes for several vibrations. The key was then snapped for six readings when the mean reading passed the cross-hair of the telescope. The mean reading was determined in each case by a computation from previous readings. It was found to be very constant. After lunch the same operation was repeated. This gave six readings of the time interval of 7 complete to and fro vibrations, with data for determining the probable error of the mean. The result was 653.45 ± 0.062 seconds. The probable error was sometimes three times as great as the above value and the mean value varied from the above value on other days by between one and two seconds. An error in the value of n might amount to three or four per cent. The cause for these variations proved to be a difficult problem. The silk threads were very loosely wound, and before they were put in place a weight equal to half the weight of the entire suspended mass was hung upon each of them for several days. They then seemed to be in permanent condition. The breaking stress was about five times that which was thus applied to them.

The causes for the variation in the time of vibration were thought to be possibly due to a breaking of some of the fibers in the threads which might result in an entanglement between the two threads, or which might result in an unequal division of the load between them. It was sought to eliminate the former source of error by applying vaseline to the threads. This did not appre-

ciably change the result. It was finally decided to check the results above described by placing the large masses on alternate sides of the suspended masses and observing the deflection due to gravitational attraction.

In order to maintain equality of stresses in the two threads, which had been hung around a hook attached to the torsion head, they were hung around a pulley, having a diameter of one inch. Below were two adjustable pulleys. The threads approached each other around these two pulleys, and their distance apart could be so varied as to make the threads parallel within the long suspension cylinder. The metal shield before described was replaced by one having equal width from end to end. The top, bottom and ends were of wood $\frac{7}{8}$ inch in thickness. A sketch of this wood frame is shown in vertical section in Fig. 1.

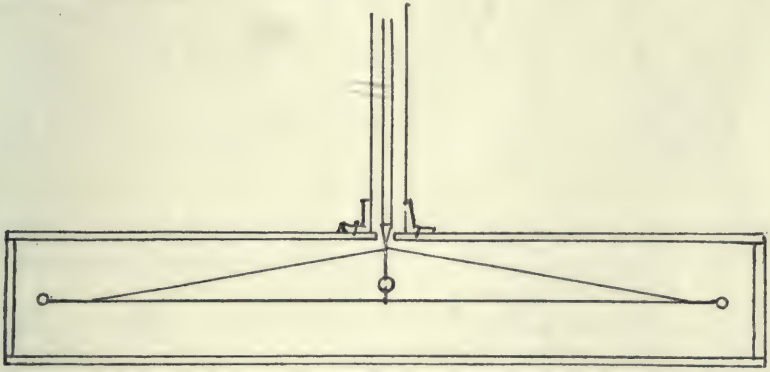


Fig. 1.

This wood frame was varnished with shellac and all points of contact of its parts were closed. The sides of this frame were each closed by two layers of heavy cardboard outside of which was a sheet of flexible tinned iron. They were clamped to the wooden frame by means of wood bars screwed to the bottom, top and ends. The edges of the cardboard were then sealed by means of beeswax applied by means of a hot iron. The entire device as thus described was then enclosed by a metal shield.

A cross section through one of the suspended masses is shown in Fig. 2.

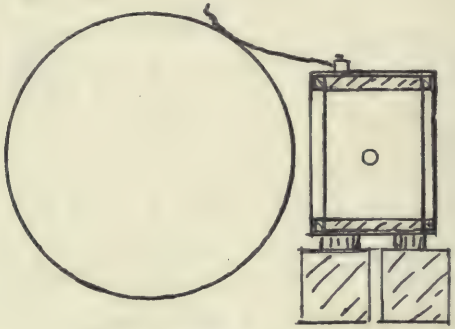


Fig. 2.

This outside metal shield was not air-tight. It was formed of sheets of flexible tinned iron, the parts of which overlapped. They were tied in place by windings of twine. It was considered an advantage to allow convection currents which might form in the layer of air between the two sheets of metal forming the sides of the enclosing case some opportunity to escape into the outer air.

The large masses M were thus separated from the suspended masses m' by two superposed sheets of cardboard and a sheet of metal, which were clamped and sealed to the wood frame of Fig. 1, a layer of air about $\frac{7}{8}$ inch in thickness, and the outer sheets of metal, forming part of the metal shield enclosing the entire device.

Both of the masses M, and the shield around the suspended masses, were insulated as before described. The large masses and the shield around the suspended masses were connected by means of large copper wires. Between the masses M, and the shield were sheets of glass, not shown in Fig. 2.

In the work to be described, the air around the large masses and screen was electrified by a noiseless discharge from 800 pin points which were mounted in strips of metal hung upon insulated metal rods three feet from the

large masses and screen. A sketch of this arrangement is shown in Fig. 3. The sheets of metal which carried these pins were punched with small holes, through which

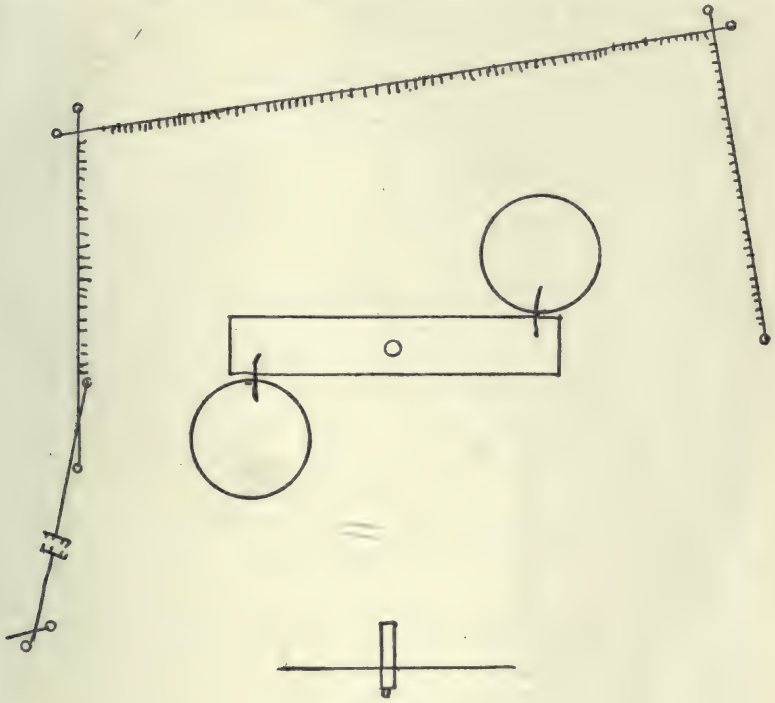


Fig. 3.

the pins were inserted and the heads were then soldered to the sheets of metal, which were then hung upon the insulated rods by metal hooks. At one end this line of rods terminated in a disc of metal upon which 150 pins were mounted. Facing this disc was a duplicate, the points of the pins in the two discs being three or four inches apart. This last named disc was directly connected with one terminal of an influence machine in an adjoining room, the other terminal being grounded on a water pipe. There were no condensers attached to the machine, and the knobs were widely separated. There were no gaps in the line of conductors. The machine was

enclosed in a glass case containing drying material, and it was driven by a single-phase motor. Placing the large masses in the position shown in Fig. 3 at the time when the work to be described began, increased the scale reading by 0.40 cm.

An illustration of the results obtained is shown in Plate XLV. In each case the masses had been grounded during the preceding night. The scale was displaced in order that the two diagrams might be shown on the same plate, without interference. On the lower diagram the arrangement of apparatus was as shown in Fig. 3. The hour of the day is laid off upon the horizontal axis. The scale reading in cm. is along the vertical axis. One mm. represents an angle of 2.6 minutes of arc. The negative terminal was applied at 9:38 a. m. On the diagram the arrow indicates the time. At 10:12 a. m. the terminals were reversed, an operation which required a few seconds of time. At 11:30 the machine was disconnected. There was evidence shown in the drop in the reading at 11:20 that the reading would begin to decrease. The upper diagram of this plate shows results obtained on May 4. Here the positive terminal was first applied at 9:35 a. m. The terminals were reversed at 10:24 and the machine was stopped at 11:20, the readings being continued to 12:05 p. m. In this work the conductors upon which the 800 pins were supported were directly connected with the large masses and shield.

When direct contact was made between the pin-conductors and the large masses, the changes took place more rapidly than when the air surrounding the masses was supercharged with negative corpuscles emitted from the pin points, or when the reverse action took place, this alone being depended upon to change the potential of the masses. The most interesting feature of this work is the complete elimination of the possibility that the apparent decrease in the attraction between these masses was due to the convection currents of air resulting from heat effects. Reversing the terminals would not reverse these heat effects.

The possibility that one terminal of the machine produced greater heat effects than the other, the deflecting effect being decreased when the terminal producing the lesser heating effect was applied is also eliminated. It matters not which terminal is first applied. The result is the same, and has been obtained many times.

During the afternoon of May 4 the operation represented in the upper curve of Plate XLV was repeated, the positive terminal being first applied. A result of precisely the same kind was obtained.

The upper curve of Plate XLV also means that the gravitational attraction between the masses at 9:35 a. m. had been decreased by about 110% at 10:10 a. m. Gravitational attraction had been decreased to zero, and had then been converted into a repulsion. An hour later it had regained its initial value. On the afternoon of June 1, at 2:30 p. m., it was decided to change the electrical condition of the suspended masses. One of the end caps forming the outer metal shield of Fig. 2 was removed. A hole which had been bored through the wood frame, and which had been closed by a rubber stopper, was opened. A glass tube was passed through the opening, about two centimeters beyond the inner surface of the wood frame. A copper wire to the end of which the head of a pin had been soldered, was passed through the tube, the point of the pin projecting slightly beyond the end of the tube. The wire was about six inches in length. The apparatus was arranged as shown in Fig. 3. The positive terminal of the machine was used in draining negative corpuscles from the air within the shield around the suspended masses. A slow change of 1.2 cm. or 12 scale divisions in the scale reading was produced. The terminal was disconnected when this deflection had been produced, and the machine was stopped. The tube was removed, the end cap of metal was replaced and the large masses and shield and the pin-point conductors were grounded until the next day. The mean reading had not been appreciably changed.

At 10:25 a. m., June 2, readings were taken until 10:43 a. m. The suspended masses were at rest.

The positive terminal was then applied. The result is shown in Plate XLVI.

The arrangement of the apparatus was that shown in Fig. 3. A sudden decrease in the attraction occurred. It was so sudden that forced vibrations were impressed upon the suspended masses. The vibrations were small, and only occasional readings of consecutive extremes were recorded. At 2:20 p. m. the terminals were reversed and at 2:32 p. m. direct contact of the pin-point conductors and the large masses and shield was made. The attraction at once increased very rapidly. The absolute zero of potential was reached and passed in a less time than that of a semi-vibration. Forced vibrations were impressed upon the suspended masses as the attraction began to decrease. These vibrations were observed, and the extremes were read until 3:30 p. m. The masses were then being repelled by a force nearly twice as great as the initial gravitational attraction. Direct contact between the discharge points was removed, but the masses were not grounded. On Monday, June 4, at 9:20 a. m., the masses were vibrating over a very small arc (about one scale division). Readings were taken at some of the extremes of vibration, which were sufficient in number to show that the mean reading was constant until 11 a. m. These readings are represented in Plate XLVII. The masses were still repelling each other, with a force about 50 per cent. greater than the initial attraction on the morning of June 2. This conclusion seemed beyond belief at the time but subsequent results on that day seemed to make it a necessary conclusion. At 11:03 a. m. the positive terminal was applied and direct contact between the large masses and the pin-point conductors of Fig. 3 was made. The time is represented by the arrow marked + D. C. on Plate XLVII.

At once the attraction began to increase. The masses were swaying in the opposite direction at the time when

contact was made. A maximum reading was obtained at 11:18 a. m. and the masses swayed in the opposite direction during the next 14 minutes. Forced vibrations were again impressed upon the suspended masses, but they were less violent in character than those at the close of the observations represented in Plate XLVI. At 12 observations were discontinued until 12:48 p. m., when the reading showed only a slight decrease. At 1:00 p. m. the terminals were reversed and the direct contact was removed. The conditions then were as represented in Fig. 3. At this time the apparent decrease in the initial attraction which existed at the beginning of the observations on June 2, was about 340 per cent. In other words the apparent repulsion was then more than twice the initial attraction. This conclusion seems to be fully justified by the amazing increase in the attraction which at once resulted. At 1:53 p. m. direct contact between the pin-point conductors and the shield and large masses was made by dropping a wire into position. It was removed at 2:02 p. m. Forced vibrations were again impressed upon the suspended masses. The machine was stopped at 2:19 p. m. and I was called away for an hour. A few readings taken between 3:12 and 3:22 p. m. shown at the close of Plate XLVII indicate that the attraction had then approached closely to the initial value on the morning of June 2.

It will of course be understood that no attempt has been made to secure results of precision in this work. The only aim has been to determine whether or not it would be justifiable to construct the much more expensive apparatus which will be required for such results. The suspended masses must be capable of being electrified independently and the enclosing walls must surround them in symmetrical form, so that their inductive action will not produce deflection of the suspended masses. If they are suspended in highly rarefied air, it may be necessary to use a metal wire rather than a quartz fiber, which must then be attached to an insulated torsion head. A

modified form of the apparatus used by Boys will be required. The necessity for such a construction seems to be justified by the evidence already obtained, that if the potential of either of the attracting masses M and m' is zero absolute, gravitational attraction between them will not be affected by varying the potential of the other mass. The gravitation, constant as it has been determined by methods which made use of some form of the Mitchell-Cavendish apparatus, would have a maximum value when either or both of the masses had a potential of zero absolute.

Neglecting the inductive effect which electrified masses have upon each other, it is possible that the amended equation for gravitational attraction between them is

$$A = K \frac{m\,m'}{r^2} - K' \frac{Q\,Q'}{r^2}$$

It seems possible that the effect of the charges Q and Q' upon gravitational attraction between the masses m and m' may be a surface effect. If so the values of Q and Q' may be replaced by RV and $R'\,V'$, where R and R' are the radii of the two masses and V and V' their potentials due to those charges.

The above equation may also be written

$$A = K\left(1 - \frac{n}{100}\right)\frac{m\,m'}{r^2}$$

Here it is assumed that the masses are so electrified as to diminish their normal attraction for each other by n per cent. From these two equations the values of m and m' being replaced by their values in terms of volume and density.

$$K' = K\,\frac{n}{100}\,\frac{16}{9}\,\frac{\pi^2\,\rho^2\,R^2\,R'^2}{VV'}$$

If this equation really represents the conditions imposed upon the masses, it appears that for any given decrease in gravitational attraction the potentials of the masses must be directly proportional to the surface areas

of the masses. Small planets having high and perhaps varying potentials might not follow Newton's law. The value of n would be large and variable.

In the work represented in Plate XLVI, if we assume that when n was 100, the attraction between the masses being reduced to zero, the potential of the large masses was 30,000 volts, or 100 E. S. C. G. S. units, and that of the suspended masses was 10 volts or 1/30 E. S. C. G. S. unit, then the last equation would give for K':

$$K' = 165800\ K$$

This result is based upon assumptions and estimates. One inference may be drawn from it. There is nothing here to indicate that the force whose action is represented by Newton's term, should not be the main factor in determining the motion of the masses in our planetary system.

The large masses represented in Fig. 3 were replaced by boxes of metal, filled with loose cotton batting. They rested upon insulators. They were separated from the screen by sheets of glass, and were put in metallic contact with it by means of copper wires. Precisely the same treatment was applied to this system as was given when the large masses were in place. No change in the position of the suspended masses could be detected.

The large masses being in position as before described, spring contact brushes were fastened to the blocks of wood upon which the large masses rested. They made contact with the large masses at points midway between the top and bottom of the spheres. A direct current of 20 amperes was sent through the two large masses. The axis of the line of flow was in one case practically coincident with the line through the centers of gravity of the two masses nearest to each other. The direction of flow was either from the outside contact, to the one nearest the screen, or the reverse, the direction of flow being reversible by means of a double switch. The screen was insulated from the two large spheres. No effect upon

the suspended masses could be detected. If any effect was produced it was very small. The large masses were turned 90° in position, with a like result.

An alternating current of 20 amperes was applied. No effect could be detected when the masses were in the latter position. When the lines through the points of contact of the brushes with the large spheres was coincident practically with the line through the centers of gravity of the two masses nearest to each other, the gravitational attraction was quickly reduced to zero, and made negative. The repulsion was about 50 per cent of the normal attraction. To bring about this result required about fifteen to twenty minutes of time. When the double switch was opened, so that the large masses were wholly separated from the source, and the masses were grounded it required between two and three hours for the large masses to recover from the shock which they had received. This has been repeated many times, with no discordant results. It may be that the parts of the large spheres which are most affected by the alternating current are those parts near the brushes. If there are heat effects, they tend to oppose the observed effect. Burning candles replacing the large masses cause a change in the reading in the opposite direction from that of the alternating current, the glass plates being removed. This is due to convection currents within the screen.

The work here described has been done in a private laboratory in the second story of Eads Hall, now occupied by the physics department of Washington University.

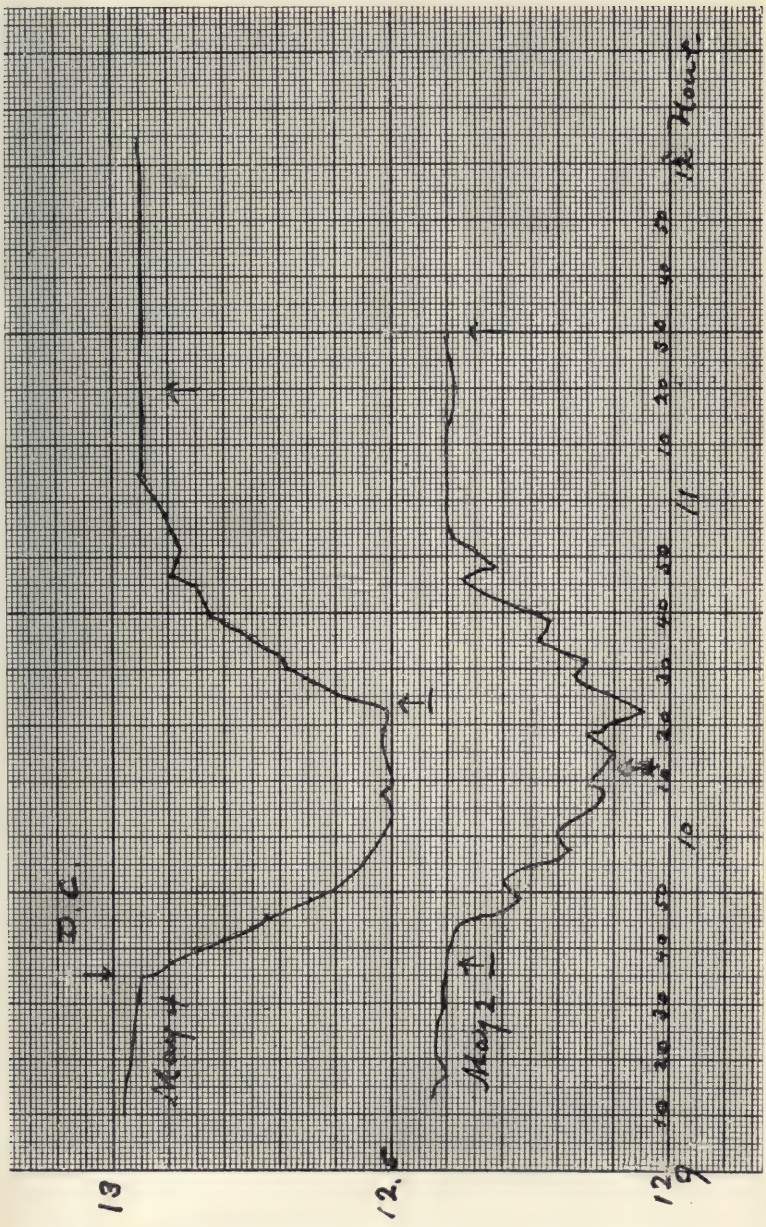
My thanks are due to the Carnegie Institution of Washington for meeting the expense of this work.

EXPLANATION OF PLATES.

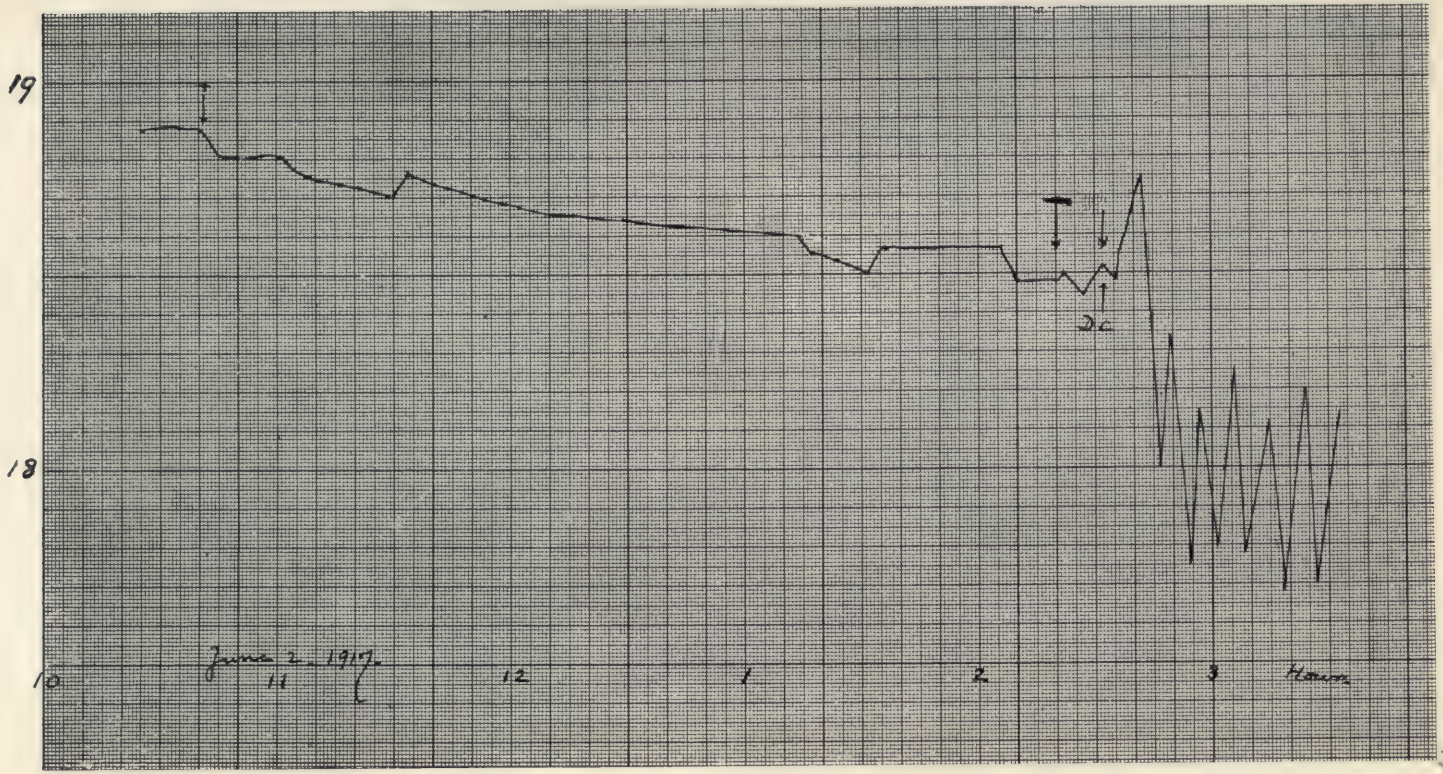
Plate XLV. Variation in Gravitational Attraction.
Plate XLVI. Variation in Gravitational Attraction.
Plate XLVII. Variation in Gravitational Attraction.

Issued November 8, 1917.

192.1



VARIATION IN GRAVITATIONAL ATTRACTION



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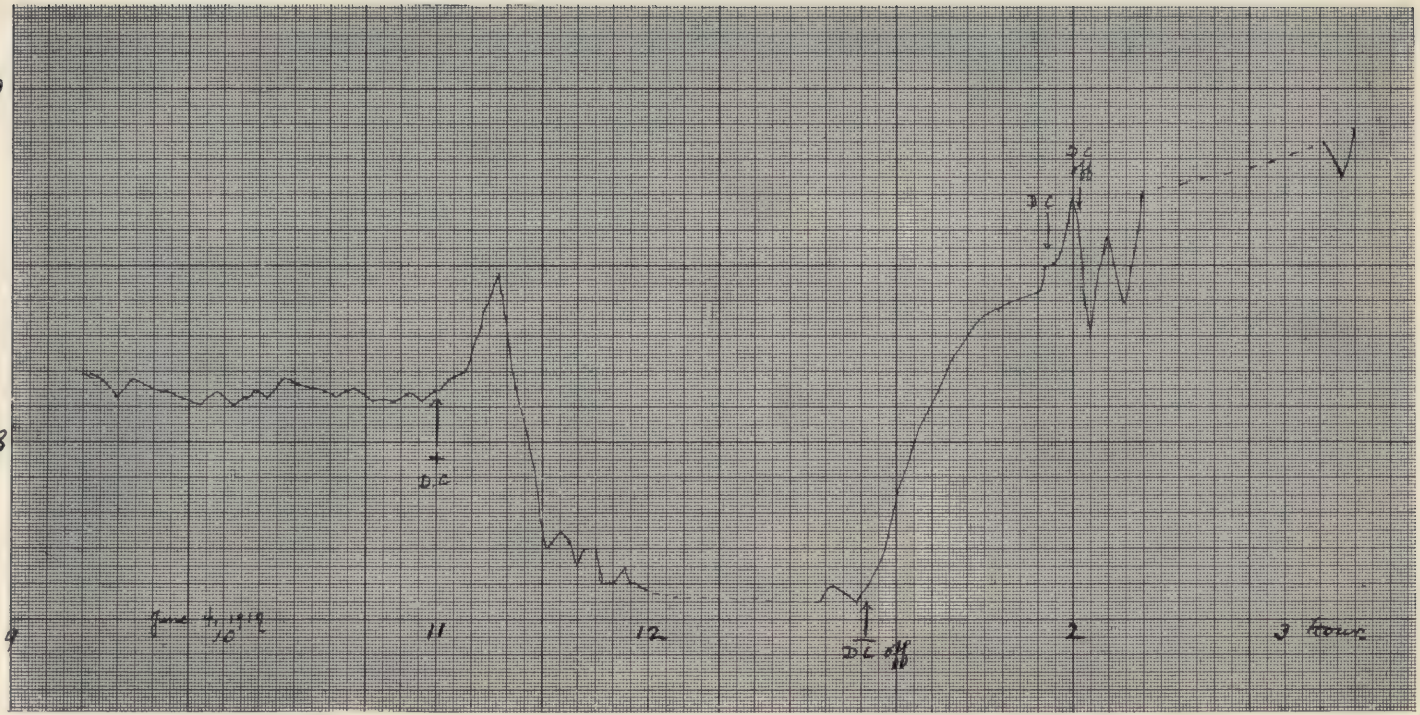


VARIATION IN GRAVITATIONAL ATTRACTION

GRAPHICAL ALGEBRA INVOLVING FUNCTIONS OF THE n^{th} DEGREE.

FRANCIS E. NIPHER.*

In the study of algebra, there is a strong tendency among the young learners to follow rules, without giving serious attention to the fundamentals upon which rules are based. There are many graduates in algebra who could at once answer the question, What is the area of the square, whose sides are $x - a$. A diagram showing the original square, with the lengths a cut off from its sides would show that when the two strips $2xa$ have been subtracted from the area x^2, the area a^2 has been subtracted twice. Therefore the final term a^2 is properly added.

It often happens that a diagram suggests something which its symbolic representation does not suggest. When they are both presented, the suggestion is still more likely to come.

As is well known, the difference between the squares of two numbers y and x is

$$y^2 - x^2 = (y - x)(y + x)$$
$$= y(y - x) + x(y - x) \quad (1)$$

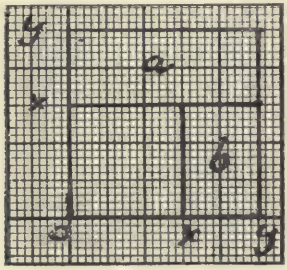


Fig. 1.

The two terms of the second member represent the areas of two rectangles marked a and b in Fig. 1. They have equal width $y - x$. Their lengths are y and x.

*Presented before The Academy of Science of St. Louis, March 18, 1918.

If we increase the lengths of the horizontal sides of these squares from y and x, to y^2 and x^2, the rectangles so resulting will have an area $y \times y^2 = y^3$, and $x \times x^2 = x^3$. In the diagram, Fig. 2, representing these rectangles the values of y and x have been assumed to be 5 and 3.

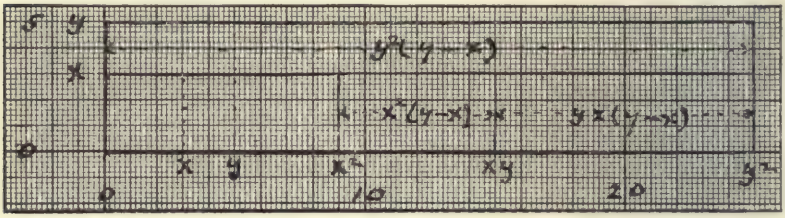


Fig. 2.

We may also describe these rectangles as being in the one case composed of five squares placed side by side, these squares each having an area of 5^2, and in the other of three squares each having an area of 3^2. We may also say that these rectangles represent values y^3 and x^3. The binominal $y^3 - x^3$ being divided by $y - x$ as in Eq. 1, we have when $y - x$ is multiplied into the terms of the quotient

$$y^3 - x^3 = y^2\ (y - x) + yx\ (y - x) + x^2\ (y - x) \quad (2)$$

The first term in the second member is represented by the area of the rectangle at the top of Fig. 2, whose length is y^2 and whose width is $y - x$. The second term is represented by the rectangle whose dimensions are x and $y^2 - yx = y\ (y - x)$. The final term has an area $x\ (yx - x^2) = x^2\ (y - x)$.[1]

Following a suggestion made by Professor Roever of the department of mathematics of Washington University, it may be pointed out that the construction of the diagram in Fig. 2 and in others that follow may be made by

[1] When one or two factors in a term represent an area, the remaining factors may be treated as multipliers. Thus $x^2\ (y - x)$ may be $2x^2$ in this case, or $x \times 2x$.

purely geometrical methods, without assuming any known values for x and y. If a straight line is drawn upon a sheet of paper, the square of which that line is a side, and the cube of which that square is to be a face, can be drawn, without any measurement of the length of the original line in terms of the centimeter or the inch.

Similarly if vertical and horizontal lines are drawn intersecting at a point which is to be common to the corners of two squares, having areas y^n and x^n we may mark upon these two axes points distant 1, x and y from the origin. These distances may have any length. The unit of length chosen may be any arbitrary and unknown length.

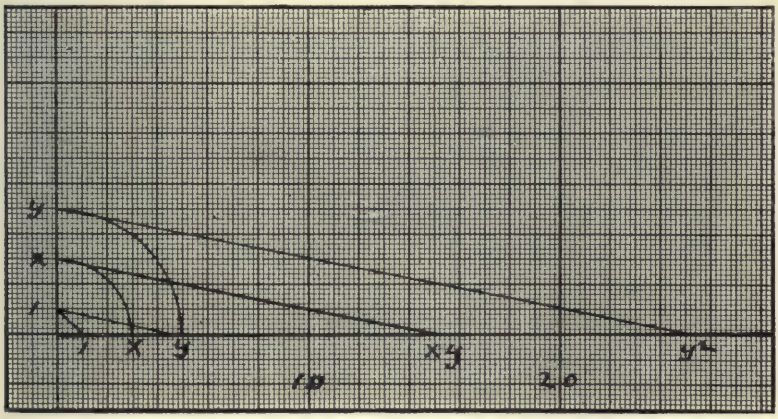


Fig. 3.

In Fig. 3 the unit when finally measured is found to be 0.5 cm. and x and y to be 1.5 and 2.5 cm.

Draw a line through the point marked 1 on the vertical axis, to the point marked y on the horizontal axis. Lines drawn parallel to this line through points marked x and y on the vertical axis, will pass through points distant xy and y^2 from the origin on the horizontal axis. These distances may then be laid off upon the vertical axis and the operation may be continued. All of the lengths in the preceding diagram can be thus laid off.

In Fig. 3 we find the lengths in centimeters to be

$$\begin{aligned} \text{Unit} &= 0.5 \text{ cm.} — 1.0 \\ x &= 1.5 \text{ cm.} — 3 \\ y &= 2.5 \text{ cm.} — 5 \\ xy &= 7.5 \text{ cm.} — 15 \\ y^2 &= 12.5 \text{ cm.} — 25 \end{aligned}$$

The lengths in terms of the chosen unit are given in the final column.

The distance x^2y may be laid off upon the axes, by drawing a line through the points marked 1 and xy. A line parallel to this through the point distant x on the vertical axis of the diagram, Fig. 3, will determine the point distant x^2y from the origin on the horizontal axis.

If we increase the width of the two rectangles y^3 and x^3 of Fig. 2 to y^2 and x^2, we shall have two squares whose areas are $y^2 \times y^2 = y^4$ and $x^2 \times x^2 = x^4$.

They are represented in Fig. 4. Figures 1 and 2 will also be identified in this diagram.

The difference between the areas of these two squares is

$$\begin{aligned} y^4 - x^4 &= (y^2 + x^2)\,(y^2 - x^2) \\ &= (y + x)\,(y^2 + x^2)\,(y - x) \\ &= y^3\,(y - x) + y^2x\,(y - x) \\ &\quad + yx^2\,(y - x) + x^3\,(y - x). \quad (3) \end{aligned}$$

The first two terms of the second member may be written

$$y^2\,(y^2 - yx) \text{ and } y^2\,(yx - x^2)$$

They are represented in Fig. 4 by the large rectangles a and b.

The two following terms of Eq. (3) may be written

$$x^2\,(y^2 - yx) \text{ and } x^2\,(yx - x^2)$$

They are represented by the rectangles marked c and d.

Figure 4 shows clearly the nature of the changes from the conditions in Fig. 1. When the sides of the two squares lying along the horizontal axis were increased to $y \times y$ and $x \times x$ as in Fig. 2, the rectangle a of Fig. 1 was

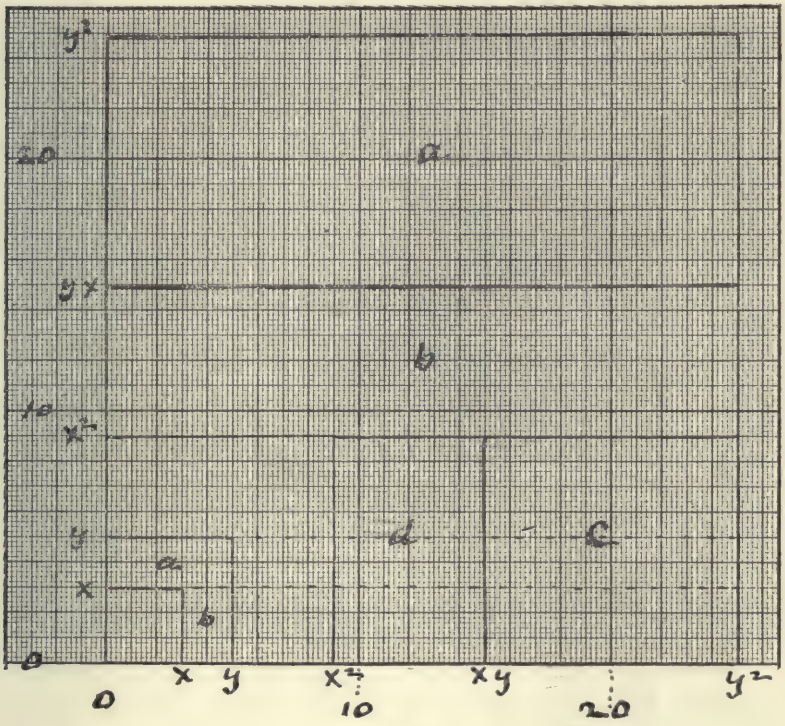


Fig. 4.

made longer and became $y \times y$ in length, but its width remained unchanged. It was still $y - x$. The rectangle b of Fig. 1 was replaced by two rectangles whose lengths were still x but in one of these rectangles, the width had increased from $y - x$ to $y^2 - yx = y\,(y - x)$ and in the other rectangle the width had increased from $y - x$ to $x\,(y - x) = xy - x^2$.

When the next change was made, from Fig. 2 to Fig. 4 the two rectangles to the right of $x \times x^2$ in Fig. 2 did not change in width but their length increased from x to

x^2. They become the rectangles c and d of Fig. 4. The narrow strip across the top of Fig. 2, shown between dotted lines in Fig. 4, was replaced by two strips marked a and b at the top of Fig. 4. Their length y^2 is the same as in Fig. 2. Their widths have increased from $y - x$ to $(y^2 - yx) = y\,(y - x)$ in one case and to $yx - x^2 = x\,(y - x)$ in the other.

These rectangles all decrease in width if x is made to approach y in value. When $x = y$ Eq. 3 shows that

$$\left(\frac{y^4 - x^4}{y - x}\right)_{x=y} = \frac{0}{0} = 4y^3 = \frac{\delta}{dy}(y^4)$$

This is the change in the area of y^4 per unit of change in y.

In Eq. (1) which is represented in Fig. 1, the values y and x which have been increased to y^2 and x^2 resulting in Eq. 2 and Fig. 2 are horizontal dimensions. This may be done by directly changing Eq. (1) to

$$y^3 - x^3 = y^2\,(y - x) + x\,(y^2 - x^2)$$

This is Eq. (2).

When the vertical dimensions y and x are changed to y^2 and x^2, the above equation becomes

$$y^4 - x^4 = y^2\,(y^2 - x^2) + x^2\,(y^2 - x^2)$$

This is one form of Eq. 3 and the resulting diagram is Fig. 4. It is of exactly the same structure as Fig. 1.

We may now increase the length of the sides of the rectangles y^3 and x^3 in Fig. 2 to y^5 and x^5, and y^4 and x^4, the values of y and x remaining unchanged.

Two rectangles having areas y^9 and x^9 are thus produced. They are shown in diagram, but not drawn to scale, in Fig. 5. If the centimeter is taken as the unit and $y = 5$ and $x = 3$ the rectangle y^9 would have sides $y^5 = 3125$ cm. and $y^4 = 625$ cm. if drawn to scale.

The difference between these areas y^9 and x^9 or $y^9 - x^9$ may be expressed by dividing by $y - x$, and multiplying this factor into the terms of the quotient.

$$\begin{aligned} y^9 - x^9 = {} & y^8 (y - x) + y^7 x (y - x) \\ & + y^6 x^2 (y - x) + y^5 x^3 (y - x) \\ & + y^4 x^4 (y - x) + y^3 x^5 (y - x) \\ & + y^2 x^6 (y - x) + y x^7 (y - x) \\ & + x^8 (y - x) \ldots\ldots\ldots\ldots\ldots (4) \end{aligned}$$

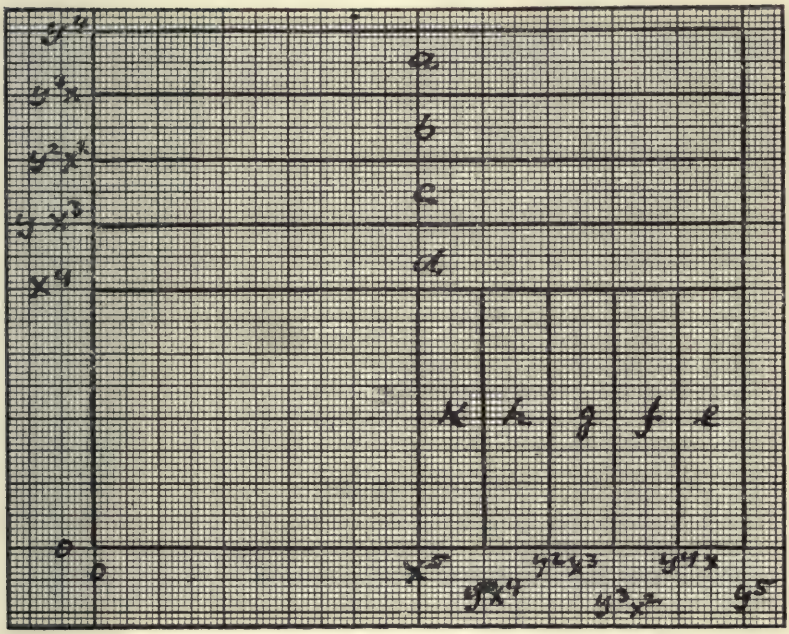


Fig. 5.

The first four terms may be written

$$\begin{aligned} y^5 \times y^3 \quad (y - x) \text{ or } y^5 (y^4 \quad - y^3 x) \\ y^5 \times y^2 x \ (y - x) \text{ or } y^5 (y^3 x - y^2 x^2) \\ y^5 \times y\, x^2 (y - x) \text{ or } y^5 (y^2 x^2 - y\, x^3) \\ y^5 \times x^3 \quad (y - x) \text{ or } y^5 (y\, x^3 - x^4) \end{aligned}$$

These terms represent the areas of four rectangles, marked *a*, *b*, *c* and *d* in Fig. 5. They have a common length y^5.

The remaining five terms of Eq. (4) may be written

$$\begin{aligned}
&x^4 \times y^4 \quad (y-x) \text{ or } x^4 (y^5 \quad - y^4 x) \\
&x^4 \times y^3 x \ (y-x) \text{ or } x^4 (y^4 x \ - y^3 x^2) \\
&x^4 \times y^2 x^2 \ (y-x) \text{ or } x^4 (y^3 x^2 - y^2 x^3) \\
&x^4 \times y\, x^3 \ (y-x) \text{ or } x^4 (y^2 x^3 - y\, x^4) \\
&x^4 \times \quad x^4 \ (y-x) \text{ or } x^4 (y\, x^4 - x^5)
\end{aligned}$$

These terms represent the five rectangles *e, f, g, h, k* of Fig. 5. They have a common length x^4.

If we now increase the shorter sides of these rectangles from y^4 and x^4 to y^5 and x^5, the difference between the areas of the two squares thus formed will be

$$\begin{aligned}
y^{10} - x^{10} = y^9 \quad &(y-x) + y^8 x \ (y-x) \\
&+ y^7 x^2 \ (y-x) + y^6 x^3 \ (y-x) \\
&+ y^5 x^4 \ (y-x) + y^4 x^5 \ (y-x) \\
&+ y^3 x^6 \ (y-x) + y^2 x^7 \ (y-x) \\
&+ y\, x^8 \ (y-x) + \quad x^9 \ (y-x) \qquad (5)
\end{aligned}$$

The first five terms may be written

$$\begin{aligned}
&y^5 \times y^4 \quad (y-x) = y^5 (y^5 \quad - y^4 x) \\
&y^5 \times y^3 x \ (y-x) = y^5 (y^4 x \ - y^3 x^2) \\
&y^5 \times y^2 x^2 \ (y-x) = y^5 (y^3 x^2 - y^2 x^3) \\
&y^5 \times y\, x^3 \ (y-x) = y^5 (y^2 x^3 - y\, x^4) \\
&y^5 \times \quad x^4 \ (y-x) = y^5 (y\, x^4 - \quad x^5)
\end{aligned}$$

The four rectangles *a, b, c* and *d* of Fig. 5, have been replaced by five, their lengths being y^5 as in Fig. 5. Their widths are now the same as the widths of the five rectangles *e, f, g, h,* and *k* in Fig. 5. The widths of the four rectangles *a, b, c* and *d* have all been multiplied by *y* and the last one above represented has been added.

The remaining five terms of Eq. 5 may be written

$$\begin{aligned}
&x^5 \times y^4 \quad (y-x) = x^5 (y^5 \quad - y^4 x) \\
&x^5 \times y^3 x \ (y-x) = x^5 (y^4 x \ - y^3 x^2) \\
&x^5 \times y^2 x^2 \ (y-x) = x^5 (y^3 x^2 - y^2 x^3) \\
&x^5 \times y\, x^3 \ (y-x) = x^5 (y^2 x^3 - y\, x^4) \\
&x^5 \times \quad x^4 \ (y-x) = x^5 (y\, x^4 - \quad x^5)
\end{aligned}$$

The width of these rectangles e, f, g, h and k remain as before, but their length has been made x times greater.[2]

In an arithmetic published by Dr. Daniel Adams, of Keene, N. H., in 1848, and which caused me much trouble in my youthful days, he gives a drawing of a cube, the length of the edges being 3 units. He then presents a drawing of 3^4, which he represents as three such cubes placed side by side. Then follows a drawing of 3^5, and 3^6, the latter being represented by 27 such cubes in the form of a cube whose edges are 3^2 in length. He gives a verbal description of the forms of such volumes up to "3^{18}, etc.," but he says not a word about space of 18 dimensions.[3]

All of the preceding discussion for quantities of the third degree or over, can be most interestingly presented by drawings in three dimensions. If y^3 and x^3 are represented as is usually done by cubical volumes, the geometrical significance of the three terms of Eq. 2 differs from that given in Fig. 2. It is unnecessary to explain them here.

If the lengths of x and y be increased to x^2 and y^2 we shall have two cubes whose volumes are y^6 and x^6. The difference in the volumes of these cubes will be,

$$y^6 - x^6 = y^5(y-x) + y^4x(y-x) + y^3x^2(y-x) + y^2x^3(y-x) + yx^4(y-x) + x^5(y-x) \quad (6)$$

The second member may be written

$$y^3[y^2(y-x) + yx(y-x) + x^2(y-x)]$$
$$x^3[y^2(y-x) + yx(y-x) + x^2(y-x)]$$

A reference to Eq. (2) will show that we have between the outer and inner cubes, two sets of rectangular volumes,

[2] The diagram representing Eq. 5 can be laid out upon a lawn. White twine attached to corner stakes may be used to mark boundary lines.

[3] As a matter of historical interest a reproduction of the page in which Dr. Adams gives this discussion, is reproduced at the close of this paper.

one set lying outside of the other. They are similar to those represented by the terms of Eq. (2). Each of the three dimensions of each block or volume in the outer layer has been made y times as long as in the volumes represented by the terms of Eq. (2). The similar dimensions of the inner layer have been multiplied by x.

A model of these cubes may be made as follows, assuming that $y = 5$ and $x = 3$.

The inner cube x^6 which is made of wood has dimensions $9 \times 9 \times 9$ cm. Its faces are each divided by lines into nine squares. Three blocks of wood are then to be applied to three adjoining sides. By the last three terms of Eq. (6) their dimensions are

$$\begin{aligned} xy \times xy \times x(y-x) &= 15 \times 15 \times 6, \\ xy \times x^2 \times x(y-x) &= 15 \times 9 \times 6, \\ x^2 \times x^2 \times x(y-x) &= 9 \times 9 \times 6. \end{aligned}$$

This forms a cube whose volume is

$$[x^2 + x(y-x)]^3 = (xy)^3 = (15)^3.$$

Outside of this a similar set of blocks is placed, represented by the first three terms of Eq. (6). The dimensions of these blocks are

$$\begin{aligned} y^2 \times y^2 \times y(y-x) &= 25 \times 25 \times 10, \\ y^2 \times yx \times y(y-x) &= 25 \times 15 \times 10, \\ yx \times yx \times y(y-x) &= 15 \times 15 \times 10. \end{aligned}$$

The result is a cube whose volume is

$$[x^2 + x(y-x) + y(y-x)]^3 = y^6.$$

The faces of the resulting cube should each be ruled into twenty-five equal squares, whose sides are $y = 5$.

Dr. Daniel Adams might have been more emphatic in his statements without going astray. "The 6*th*, 9*th*, 12*th*, 18*th*, etc., powers may be represented by cubes" and when so represented they have the same geometrical

significance as when the $3d$ power is so represented. Also any numerical value raised to any power, may be represented in space of two dimensions or as a straight line.

Eq. (6) may also be represented by a diagram analogous to that in Fig. 4. There will be three strip areas across the top of the square x^6, instead of the two areas a and b. Their common length is y^3. There will be three rectangles replacing c and d of Fig. 4, the height of each being x^3. The width of these strips can be found by dividing these factors into the terms of Eq. 6.

All of the terms of the developed function $y^n - x^n$ can be identified in a diagram, in which y and x are laid off on the vertical axis, and y^{n-1} and x^{n-1} are laid off along the horizontal axis. The strip a of Fig. 1 will increase in length as n increases, but its width $y - x$ will remain constant. It will be represented by the first term. Below this strip, will be a series of rectangles having a common height x. They will represent the second and succeeding terms of the developed function.

The value of $(y+x)^4$ may be represented by an area. Assume for example $y = 5$ and $x = 3$. Construct a square whose sides are $(y + x)^2 = 64$. Divide the sides into segments whose lengths are $y^2 = 25$, $2xy = 30$ and $x^2 = 9$. Draw lines across the square through the points separating these segments. The square $(y + x)^4$ will then be divided into nine rectangles, representing the six terms of the expanded binominal $(y + x)^4$. If x be considered negative, some of these rectangles must be considered negative in value. Their location in the square will be a matter of interest to the young experimenter. If in addition $y = x$, the sum of the positive and negative areas will be equal.

Issued May 9, 1918

INVOLUTION.

First power. ¶ **206.** Three feet in length (¶ 111) are a yard, linear measure; 3 in length and 3 in width, $3 \times 3 = 9$ square feet, are a yard,

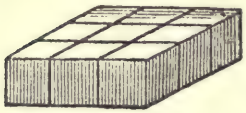
Second power. square measure; 3 in length, 3 in width, and 3 in hight, $3 \times 3 \times 3 = 27$ solid feet, are a yard, cubic measure, (¶113.)

When a number, as 3, is multiplied into itself, and the product by the original number, and so on, the several numbers produced are called *powers*, and the process of producing them is called *Involution.*

Third power. The first number, represented by a line, is called the first power, or *root;* the second, represented by a square, is called the square, or 2d power; the third, represented by a cube, is called the cube, or 3d power.

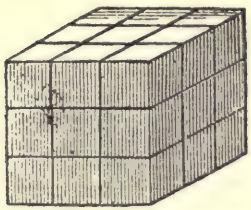
Fourth power. The 4th power of 3 is 3 times the 3d power, 3 blocks like that employed to represent the 3d power, and may be represented by a figure 3 times as large, that is, 3 feet wide, 3 feet high, and 9 feet long.

Fifth power. The 5th power, by 3 times such a figure, or one 3 high, 9 wide, and 9 long.



The 6th power, 3 times this, by a figure 9 long, 9 wide, and 9 high, or a cube.

Sixth power.



Thus it may be shown that the 9th, 12th, 15th, 18th, &c., powers, may be represented by cubes; the 7th, 10th, 13th, 16th, &c., by figures having greater length than width and hight; the 8th, 11th 14th, 17th, &c., by figures having greater length and width than hight.

To involve a number, take it as a factor as many times as is indicated by the required power.

NOTE. 1 — The number denoting the power is called the *index*, or *expo nent;* thus, 5^4 denotes that 5 is raised or involved to the 4th power.

(From Adams' Arithmetic—See p. 201.)

GRAPHICAL ALGEBRA.*

FRANCIS E. NIPHER.

In the former paper it was shown that algebraic functions of a higher order than the second degree may be represented in diagram upon a plane surface.

In the present paper the same function will be represented by widely different diagrams.

The difference between the areas of two squares having sides the length of which are y^5 and x^5 is

$$\begin{aligned} y^{10} - x^{10} = {} & y^9 \quad (y-x) + y^8 x \ (y-x) \\ & + y^7 x^2 \ (y-x) + y^6 x^3 \ (y-x) \\ & + y^5 x^4 \ (y-x) + y^4 x^5 \ (y-x) \\ & + y^3 x^6 \ (y-x) + y^2 x^7 \ (y-x) \\ & + y\, x^8 \ (y-x) + x^9 \quad (y-x) \end{aligned} \tag{5}$$

This is Eq. (5) of the former paper.

This equation may be written:

$$\begin{aligned} y^{10} - x^{10} = {} & y^5 \quad (y^5 \quad - y^4 x \ ) + y^4 x \ (y^5 \quad - y^4 x \ ) \\ & + y^4 x \ (y^4 x - y^3 x^2 \ ) + y^3 x^2 \ (y^4 x - y^3 x^2) \\ & + y^3 x^2 \ (y^3 x^2 - y^2 x^3) + y^2 x^3 \ (y^3 x^2 - y^2 x^3) \\ & + y^2 x^3 \ (y^2 x^3 - y\, x^4) + y\, x^4 \ (y^2 x^3 - y\, x^4) \\ & + y\, x^4 \ (y\, x^4 - \quad x^5) + \quad x^5 \ (y\, x^4 - \quad x^5) \end{aligned} \tag{7}$$

$$\begin{aligned} = {} & (y^5 \quad + y^4 x \ ) \ (y^5 \quad - y^4 x \ ) \\ & + (y^4 x \ + y^3 x^2) \ (y^4 x - y^3 x^2) \\ & + (y^3 x^2 + y^2 x^3) \ (y^3 x^2 - y^2 x^3) \\ & + (y^2 x^3 + y\, x^4) \ (y^2 x^3 - y\, x^4) \\ & + (y\, x^4 + \quad x^5) \ (y\, x^4 - \quad x^5) \end{aligned} \tag{7a}$$

$$\begin{aligned} = {} & (y^{10} \quad - y^8 x^2) + (y^8 x^2 - y^6 x^4) \\ & + (y^6 x^4 - y^4 x^6) + (y^4 x^6 - y^2 x^8) \\ & + (y^2 x^8 - x^{10}) \end{aligned}$$

* Continued from No. 6, Vol. XXIII. Presented by title before the Academy of Science of St. Louis, January 20, 1919.

This equation is represented in diagram in Fig. 1. The ten terms of Eq. (7) are represented by the areas of the rectangles marked with numerals 1 to 10.

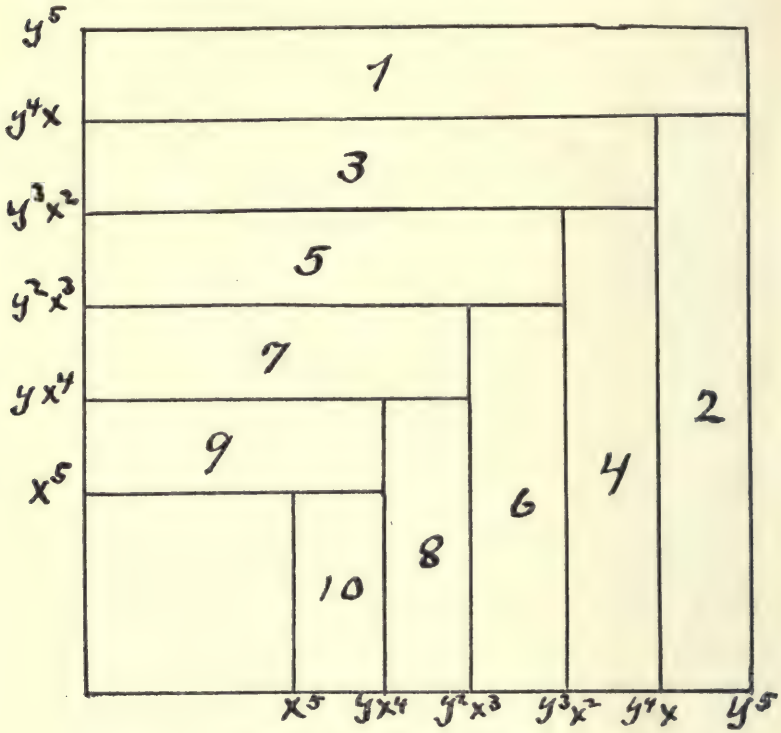


Diagram of $y^{10} - x^{10}$.

Fig. 1.

Any values may be assigned to x and y and this diagram may be drawn to scale if the assigned values are not too large, or do not differ too much from unity.

The computed values are of interest in some cases even if they cannot be laid off to scale. For example assume the values of y and x to be 5 and ¼, the unit of length being the inch. The squares y^2 and x^2 would then have sides the length of which would be 5 inches and ¼ inch.

Multiplying these sides by y^4 and x^4 the sides of the resulting squares would have lengths $y^5 = 3125$ inches

and $x^5 = 0.000976$ inch. This square would hardly be visible to the unaided eye. The width of the two strips marked 1 and 2 in Fig. 1 would be $y^5 - y^4x = 3125 - 156.25 = 2968.75$ inches. Their combined length is $y^5 + y^4x = 3281.25$. The product of these two numbers would be the difference between the areas of the two squares, y^{10} and y^8x^2.

The width of the two areas which represent the ninth and tenth terms would be $yx^4 - x^5 = 0.01953 - 0.000976 = 0.01856$. Their combined length is $yx^4 + x^5 = 0.02050$. The product of these two quantities gives the difference between the two squares y^2x^8 and x^{10}.

This diagram and the final form given to Eq. (7) shows that Eq. (5) is similar to another well known equation $y^2 - x^2 = y\,(y - x) + x\,(y - x)$.

Equation (5) may be written:

$$\begin{aligned} y^{10} - x^{10} = {} & y^5\,(y^5 - y^4x) + y^5\,(y^4x - y^3x^2) \\ & + y^5\,(y^3x^2 - y^2x^3) + y^5\,(y^2x^3 - yx^4) \\ & + y^5\,(yx^4 - x^5) + x^5\,(y^5 - y^4x) \\ & + x^5\,(y^4x - y^3x^2) + x^5\,(y^3x^2 - y^2x^3) \\ & + x^5\,(y^2x^3 - yx^4) + x^5\,(yx^4 - x^5) \end{aligned} \qquad (8)$$

In order to respond to this change the strips marked 3, 5, 7, and 9 must be extended to the right side of the square y^{10}, their widths remaining unchanged, when drawn to scale. They will then have a common length y^5. The first term in this equation is the same as in Eq. (7). The strips marked 2, 4, 6, and 8 must be correspondingly reduced in length to x^5, the strip marked 10 remaining unchanged. In this arrangement the strips marked 1, 3, 5, 7, and 9 will represent the first five terms in the equation, and those marked 2, 4, 6, 8, and 10 will represent the five final terms. As thus changed, the strip marked 9 would have an area $y^5\,(yx^4 - x^5)$. As drawn in the diagram the strip marked 5 has an area $y^3x^2\,(y^3x^2 - y^2x^3)$, which is equal to the area of strip 9 when thus extended.

The five horizontal strips when thus extended, may be considered as one strip, having an area $y^5\ (y^5 - x^5)$, and the area of the vertical strips is $x^5\ (y^5 - x^5)$. The sum of the two resulting strips is

$$y^{10} - x^{10} = y^5\ (y^5 - x^5) + x^5\ (y^5 - x^5).$$

Equation (3) is readily reduced to this form. It is entirely similar to the well-known equation

$$y^2 - x^2 = y\ (y - x) + x\ (y - x).$$

As was suggested in the former paper, the two squares y^2 and x^2 may be changed by applying the multiplying factor to the horizontal sides of the two squares. The areas remaining as in former equations, and adopting the same unit, and the same values for y and x, the area y^{10} would then be a rectangle, the vertical width of which would be $y = 5$ inches, and the horizontal side would have a length $y^9 = 1{,}593{,}125$ inches or 30.8 miles. The rectangle x^{10} would have a vertical dimension $x = \frac{1}{4}$ inch, and the horizontal dimension would be $x^9 = 0.000{,}003{,}81$ inch.

In order to adjust Eq. (5) to this change, it must be written,

$$\begin{aligned} y^{10} - x^{10} = {} & y^9\ (y - x) + x\ (y^9 - y^8x) \\ & + x\ (y^8x - y^7x^2) + x\ (y^7x^2 - y^6x^3) \\ & + x\ (y^6x^3 - y^5x^4) + x\ (y^5x^4 - y^4x^5) \\ & + x\ (y^4x^5 - y^3x^6) + x\ (y^3x^6 - y^2x^7) \\ & + x\ (y^2x^7 - yx^8) + x\ (y^8 - x^9) \end{aligned}$$

The five horizontal strip areas of the diagram are now replaced by one, the width of which is $y - x = 4.75$ inches and the length $y^9 = 1{,}593{,}125$ inches or 30.8 miles. The remaining terms are represented by a series of rectangles having a common height $x = \frac{1}{4}$ inch, and filling the space $x\ (y^9 - x^9) = \frac{1}{4}\ (1{,}593{,}125 - 0.000{,}003{,}81)$ square inches.

In planning a diagram involving squares y^4 and x^4, $1/y^4$, $1/x^4$ upon a sheet of paper having an ordinary size the lengths y^2 and $1/y^2$ may be laid off upon the two axes as may be suitable to the size of the paper. If y^2 is about 15 or 16 inches and $1/y^2$ is to be not less than one inch, the length which the unit of length must have may be determined by purely geometrical means. Draw parallel lines through the points marked y^2 on one axis and $1/y^2$ on the other axis, which cross the two axes at points equidistant from the origin. Since

$$\frac{1/y^2}{1} = \frac{1}{y^2}$$

these points will be at unit distance from the origin. If the above values of $1/y^2$ and y^2 are adopted, the unit of length thus assumed will be not far from 3¾ or 4 inches.

In terms of this unit y^2 will be about 4 units in length. The value of y in terms of this unit may be determined in a similar manner, since $1/y = y/y^2$. By this method of similar triangles the lengths $\sqrt{y}$, $1/\sqrt{y}$ and $1/y$ may be determined, all values being laid off on both axes.

The length x may then be assumed to be about midway between 1 and y. Then the lengths xy, x^2, $\sqrt{xy}$, y/x, $\sqrt{x}$, x/y, $1/x$, $1/\sqrt{xy}$, $1/x^2$ and $1/xy$ can be similarly determined by graphical methods, and laid off on both axes.

If cross-lines are now drawn through points so determined extending across the square y^4, an interesting collection of squares and rectangles will be produced. Within the square y^4 eight hyperbolae may be drawn, passing through the corners of these squares and rectangles. The points on the various curves which are so determined range from three to thirteen. The constants of these hyperbolae are y^2x^2, y^2, yx, x^2, y, x, 1, and x^2/y^2.

The difference between the areas of the two squares having sides whose lengths are $\sqrt{y}$ and $\sqrt{x}$ is

$$y - x = \sqrt{y}\ (\sqrt{y} - \sqrt{x}) + \sqrt{x}\ (\sqrt{y} - \sqrt{x}).$$

Fig. 2 is a triangle of terms needed in the construction of any diagram similar to that forming Fig. 1, for the function $y^n - x^n$, between the limits $n = 2$ and $n = 20$.

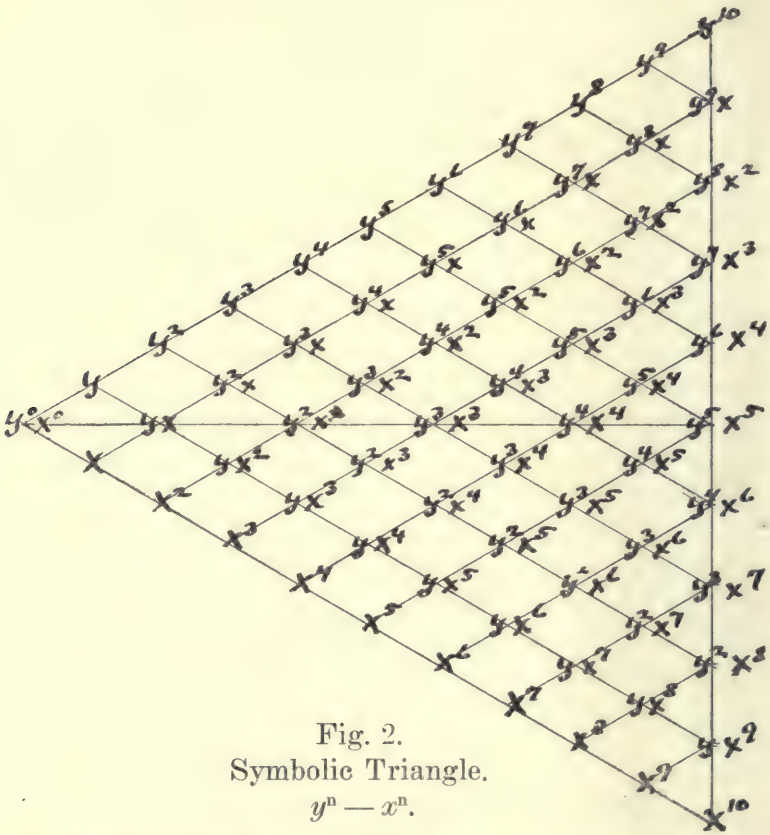


Fig. 2.
Symbolic Triangle.
$y^n - x^n$.

In the left vertical column are the lengths y and x. The difference between these two lengths, is the width of the strips between the two squares y^2 and x^2. The sum of these terms is the combined length of the two strips. The product $(y - x)\ (y + x)$ gives the value $y^2 - x^2$. These symbols may represent any value greater than zero. The distance between any two points in space cannot be less than zero. In the equation last above written they are replaced by $\sqrt{y}$ and $\sqrt{x}$. These symbols probably belong to the left of y and x in Fig. 2, approaching nearer to the apex of the triangle.

In the vertical column having y^5 and x^5 at its extremities, are the terms involved in the construction of the diagram forming Fig. 1, and representing $y^{10} - x^{10}$. The difference between the two terms y^5 and y^4x, multiplied by their sum, gives the area of the two strips marked 1 and 2 in Fig. 1. It represents the difference between the areas of the two squares y^{10} and y^8x. Similarly $(y^4x - y^3x^2)$ $(y^4x + y^3x^2)$ gives the areas of the two strips marked 3 and 4 in Fig. 1. This vertical column is a reproduction of the series of values along the co-ordinate axes in Fig. 1. The vertical column to the left contains the terms obtained by dividing $y^5 - x^5$ by $y - x$. Starting with any term in the triangle, successive terms along the line leading upwards to the right are obtained by multiplying by y. Along a horizontal line the factor is xy. Along a line leading downwards to the right the factor is x. Along a line leading vertically downwards the factor is x/y. Throughout this triangle we find the conditions which exist around the small quadrangle forming its apex where (y^0x^0) $(yx) = y \times x$. The square of any term is equal to the product of any two terms similarly placed with respect to it, along either of the eight lines of terms diverging from it.

The methods here outlined have been in use in the physics laboratory of Washington University for forty-four years. The student who knew nothing of analytical geometry was made familiar with the curves represented by the equations $y = x^n$ *and* $y = a\,x^n$. Curves were drawn for values of n of 3, 2, 1, ½, 0, — ½, — 1, and — 2. When familiar with the forms of these curves, he would be asked to "discover" by experimental methods such laws as that for the simple pendulum. The form of the curve obtained by plotting the observed values of l and t made it seem probable that the relation was represented by the equation $l = a\,t^2$. When the lines representing the values t were elongated until their length was $t \times t$, if the points so determined were in a straight line, the probability became a certainty. The conclusion is that the length of

the pendulum is directly proportional to a time interval which is t times as great as the time interval t of one vibration. It does not follow that a time interval may be squared, or that there is such a unit as a square second.

Many times a class of 50 or 60 pupils who had been with us but a few months, have been given data representing the times of rotation of planets around the sun and their mean distances from the sun, with the request that they find the relation between these quantities. In every case more than nine-tenths of the class would "discover" Kepler's third law within twenty-four hours. The plotted values made it certain that n was greater than 1. The result was a curve which made it seem probable that $t = a\, r^2$. When the values of r were squared and t and r^2 were plotted, the result was a curve which bent in the opposite direction. Therefore n must be less than 2 and greater than 1. When it was assumed that n was 3/2 or that $t^2 = a\, r^3$ and these values t^2 and r^3 were plotted, the result was a straight line.

The young discoverers were always greatly interested to learn that Kepler struggled with this problem for seventeen years after he was in possession of the data which they had received, before he discovered the relation between these variables. Of course after students have become familiar with logarithms, and they wish to find the value of n in the equation $y = a\, x^n$, the equation may be written

$$\log y = \log a + n \log x.$$

When $\log y$ and $\log x$ are plotted as co-ordinates, a stranght line will be obtained whatever the value of n may be if the above equation holds. The slope of that line is the value of n. This method of instruction is far better than the one which requires the student to test the equation given in his text-book. The student should be put in possession of methods which enable him to discover laws, even if he is not the first to discover them.

Issued January 23, 1919.

A STUDY OF THE PROPERTIES OF INTEGRAL NUMBERS.*

FRANCIS E. NIPHER.

In the 1917 edition of A History of Elementary Mathematics, pp. 32–3, Cajori refers to the work of Nicomachus, who lived about A. D. 100, as follows:

"He gives the following important proposition: All cubical numbers are equal to the sum of consecutive odd numbers. Thus, $8 = 2^3 = 3 + 5$; $27 = 3^3 = 7 + 9 + 11$; $64 = 4^3 = 13 + 15 + 17 + 19$."

It seemed probable that such interesting relations did not end so abruptly as this statement might indicate, although information along this line seems to be lacking in modern text-books and mathematical dictionaries.

A series of consecutive numbers and likewise of consecutive even numbers yielded no results of this character.

It was found that a series of consecutive odd numbers from unity to any odd number y satifies the equation

$$1 + 3 + 5 + 7 + \ldots\ldots\ldots y = \left(\frac{1+y}{2}\right)^2 = N^2$$

where N is the number of terms in the series. The table of numbers here given shows the relation of these numbers. In Chrystals' Algebra, Vol. I, p. 467, it is stated that this proposition was known to the Greek geometers. It is stated as follows: "The sum of any number of consecutive odd integers beginning with unity is the square of their number." A table of squares furnished the necessary data for a study of the subject. It was at once apparent that any number x raised to any degree n where n is an even number could be represented as the sum of an arithmeti-

TABLE I.

y	
1	
3	$4 = 2^2$
5	$9 = 3^2$
7	$16 = 4^2$
9	$25 = 5^2$
11	$36 = 6^2$

*Presented before the Academy of Science of St. Louis, Jan. 19, 1920.

cal series of consecutive odd numbers, the first term of which is unity and the final term of which is

$$l = 2x^{\frac{n}{2}} - 1 \qquad (1)$$

and that the number of terms in the series is

$$N = x^{\frac{n}{2}} \qquad (2)$$

The summation value is

$$\frac{1+l}{2} N = x^n = N^2 \qquad (3)$$

When n is an odd number, such a series will represent x^n if x is the square of some integral. The sum of a consecutive series of odd numbers from 1 to 15 is 64. The final term and the number of terms satisfy equations (1) and (2) above when $x = 8$ and $n = 2$, when $x = 2$ and $n = 6$, or when $x = 4$ and $n = 3$. The values of l and N can also be computed and yield the same results for 64^2, 8^4, 4^6, 2^{12}, and 16^3. Table II, adjoining, represents the series for $x = 2$ and 3 for various values n.

The result obtained by Nicomachus indicates that when n is an odd number the first term of the series of consecutive odd numbers which is to have a sum x^n should be greater than unity. The results in Table III were readily obtained by an inspection of the column of odd numbers and the summation of various groups of consecutive terms. The values of the first and last terms of the series were found to be

$$a = x^{\frac{n+1}{2}} - x^{\frac{n-1}{2}} + 1$$

$$l = x^{\frac{n+1}{2}} + x^{\frac{n-1}{2}} - 1 \qquad (4)$$

The number of terms in the series is

$$N = x^{\frac{n-1}{2}}. \qquad (5)$$

TABLE II.

x^n

$x=2$					$x=3$		
2^2	2^4	2^6	2^8	2^{10}	3^2	3^4	3^6
1	1	1	1	1	1	1	1
3	3	3	3	3	3	3	3
4	5	5	5	5	5	5	5
	7	7	7	7	9	7	7
	16	9	9	9		9	9
		11	11	11		11	11
		13	13	13		13	13
		15	15	15		15	15
		64	17	17		17	17
			19	19		81	19
			21	21			21
			23	23			23
			25	25			25
			27	27			27
			29	29			29
			31	31			31
			256	33			33
				35			35
				37			37
				39			39
				41			41
				43			43
				45			45
				47			47
				49			49
				51			51
				53			53
				55			729
				57			
				59			
				61			
				63			
				1024			

A verification of these equations is shown in the fact that

$$\frac{a+l}{2}N = x^n. \qquad (3)$$

This is equation (3). From equation (5) we have

$$x^n = xN^2,$$

which, with equation (3), gives the result

$$\frac{a+l}{2} = xN. \qquad (6)$$

In the former case, where $a = 1$ and n is an even number, equation (3) gave

$$\frac{1+l}{2} = N.$$

Equation (5) may be readily obtained by inspection, after the results of Table III are obtained, and it is readily seen that the values of a and l in equations (4) may also be written

$$\begin{aligned} a &= Nx - N + 1 \\ l &= Nx + N - 1. \end{aligned} \qquad (7)$$

In Table IV the group of terms having a summation value 2^9 is reproduced, and the summation values from $a = 17$ to each succeeding term are given in the second column. In the third column the first factor is the number of terms that have been added from and including $a = 17$ to the various succeeding terms, and the second factor is the average value of the first term, 17, and subsequent terms. The result reached in Eq. (6) is shown in the final term of the series, where the final term l is 47.

For any value of x the number of terms in the series when n is an even number, is the same as in the series for the same value of x when n is an odd number and one unit greater in value. Table V gives the numerical values for the quantities represented in the above equations for $x = 2$ and $x = 3$ for values of n from 2 to 13.

It may be pointed out that when x is the square of

TABLE III.

x^n

$x=2$				$x=3$			
2^3	2^5	2^7	2^9	3^3	3^5	3^7	
3							
5	5						
8	7			7			
	9	9		9			
	11	11		11			
	32	13		27			
		15					
		17	17				
		19	19		19		
		21	21		21		
		23	23		23		
		128	25		25		
			27		27		
			29		29		
			31		31		
			33		33		
			35		35		
			37		243		
			39				
			41				
			43				
			45				
			47				
			512				
						55	
						57	
						..	
						..	
						..	
						..	
						107	
						2187	

TABLE IV.

$x^n = 2^9 \qquad a = 17$

l	$s = N\frac{a+l}{2}$
19	$36 = 2 \times 18$
21	$57 = 3 \times 19$
23	$80 = 4 \times 20$
25	$105 = 5 \times 21$
27	$132 = 6 \times 22$
29	$161 = 7 \times 23$
31	$192 = 8 \times 24$
33	$225 = 9 \times 25$
35	$260 = 10 \times 26$
37	$297 = 11 \times 27$
39	$336 = 12 \times 28$
41	$377 = 13 \times 29$
43	$420 = 14 \times 30$
45	$465 = 15 \times 31$
47	$512 = 16 \times 32 = 2^9$

some integral number, the value of x^n may be represented by either of the systems above described. For example of $x = 25$ and $n = 2$ and the first term of the series be taken as unity, the final term will be

$$l = 2 \times 25^{\frac{2}{2}} - 1 = 49.$$

The sum of the series will be 625. The number of terms will be 25. The sum of the series is equal to the square of the number of terms, as is shown in Eq. (3).

If the second method above discussed be adopted, equations (4) give as the first and last terms

$$a = 25^{\frac{3}{2}} - 25^{\frac{1}{2}} + 1 = 121$$
$$l = 25^{\frac{3}{2}} + 25^{\frac{1}{2}} - 1 = 129$$

The number of terms will then be

$$N = 25^{\frac{2-1}{2}} = 5.$$

The sum of the series, or 625, will then be x times the square of the number of terms, as is shown in the former discussion.

Any number which is in the second column of Table I can be thus treated.

TABLE V.

		$x=2$				$x=3$		
n	x^n	N	a	l	x^n	N	a	l
2	4	2	1	3	9	3	1	5
3	8	2	3	5	27	3	7	11
4	16	4	1	7	81	9	1	17
5	32	4	5	11	243	9	19	35
6	64	8	1	15	729	27	1	53
7	128	8	9	23	2,187	27	55	107
8	256	16	1	31	6,561	81	1	161
9	512	16	17	47	19,683	81	163	323
10	1,024	32	1	63	59,049	243	1	485
11	2,048	32	33	95	177,147	243	487	971
12	4,096	64	1	127	531,441	729	1	1457
13	8,192	64	65	191	1,594,323	729	1459	2915

The series having a sum 3^3 appears in Table V as computed from equations (4). The first and last terms are $a=3$ and $l=7$. This is one of the results of Nicomachus.

It is therefore apparent that any integral number raised to any power can be represented as the sum of a consecutive series of odd numbers.

In the discussion which followed the presentation of this paper, Dr. C. H. Danforth suggested that the numerical values represented in Table I might be represented graphically, as is done in the diagrams at the top of Fig. 1. Starting with a small square at the upper left-hand corner, having unit area, a series of equal squares representing consecutive odd numbers are added in the three diagrams on the right. The added areas are in each

case marked by small dots in the middle. The resulting areas are 2^2, 3^2, and 4^2. This may be the way in which the Greek geometers arrived at the results in Table I of this paper.

If the area marked 2^2 in Fig. 1 is multiplied by *2*, the resulting area will be half the area of the square marked 4^2, or 2^4. If this area is again multiplied by *2*, the resulting area will be equal to that of the square marked 4^2. It will be 2^4. It has long been known that $2^4 = 4^2$. At the bottom of this plate is a square area, having within it a rectangular area whose sides have a length 4 and 1. If this area be multiplied by *4*, the resulting area will fill the lower left-hand quarter of the square. The resulting area will be 4^2. If this area be again multiplied by *4*, the resulting area will be 4^3. If we start with the lower half of the rectangular area having sides 2 and 1, and multiply this area by 2, the resulting area will have sides 1 and 4. Its area will be 2^2. Multiplying again by *2*, the resulting area will be one-half the area of the square in the lower left-hand corner of this diagram, or 2^3. Continuing the operation we shall find that the area of the square marked 4^3 is also 2^6. By reference to the diagram above it will appear that the resulting area is also 8^2.

Small cubes, the six faces of each having unit area, may be placed on the 64 squares in the two lower diagrams of Fig. 1. The volume upon each large square will be 8^2 units. If the cubes resting on the 48 unit areas in the two upper quarters and the lower right quarter of the large squares be superposed on the other quarter, the volumes of the two cubes resulting will be 4^3.

Added Feb. 25, 1920.

It will be observed that if the numeral 1 be dropped from the exponents in Eqs. (4) and (5), these equations become equations (1) and (2), the value *a* becoming unity.

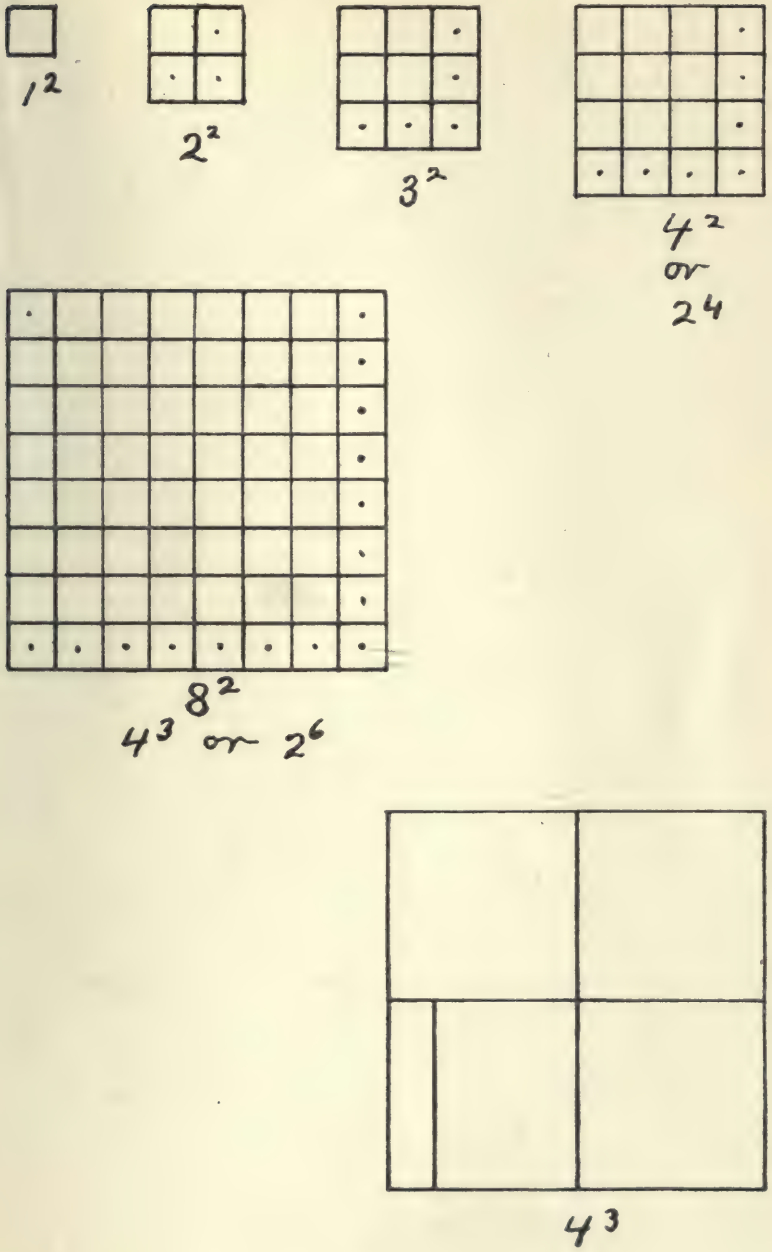


Fig. 1.

NEW EVIDENCE OF A RELATION BETWEEN GRAVITATION AND ELECTRICAL ACTION, AND OF LOCAL CHANGES IN THE ELECTRICAL POTENTIAL OF THE EARTH.*

FRANCIS E. NIPHER.

In the work to be here described, the apparatus used was a modified form of that used by Cavendish, as shown in the former paper, published by the Academy of Science of St. Louis, Vol. XXIII, pp. 183-4-5.

The wood frame was in this case covered with tin-foil, within and without. The sheet metal forming the sides of the shield were clamped to the wood frame, by bars of wood which were also covered with tin-foil. All joints were sealed with wax before the tin-foil was put in place. The whole shield was then surrounded by two end caps of metal which meet at the middle of the shield and are sealed together by means of tin-foil. A layer of air was thus formed between the two metal shields surrounding the suspended masses. Either of these two metal shields was considered ample protection to prevent the suspended masses from being acted upon electrically by the large masses. The layer of air between the two shields was designed to diminish convection effects within the shield due to changes in the temperature of the room, and changes in the temperature of the air within the room were made as small as possible, by cutting off all sources of artificial heat. It did not usually vary more than 1.5 degrees C. during the day. The temperature was determined by means of a thermometer placed near the large masses. The reading was by means of a telescope. The reading could be made accurately to tenths of a degree C. and hundredths of a degree could be estimated with fair precision. The air within the shield was

electrically charged by means of a wire armed with a pin which was thrust through a glass tube which was thrust through the end of the shield about an inch above the level of the suspended masses, and was sealed in place. The inner end of the tube was drawn to a small diameter, being only large enough to admit the end of the pin. This could be withdrawn at any time and the outer end of the tube could be covered with a metal tube which was closed with a metal plug at its outer end.

Convection effects, due to changes in temperature, have been very carefully studied. When the masses have not been electrically charged for several days, the rise in the temperature of the room during the day caused a very slow increase in the scale reading which determined the position of the suspended masses. This change in position decreases the distance between the suspended masses and the large masses. When a door opening into the hallway was opened for four minutes this change is larger and more abrupt. When an outside window was opened, admitting cold air, a sudden decrease in the reading results.

The room containing the apparatus was always entered from an adjoining room, from which heat from the heating system was wholly cut off.

In order to decrease convection effects, the large masses and shield were covered on all sides with a pile of cotton batting, forming a layer of about six to eight inches in thickness. This was permissible by reason of the fact that the electric machine in the adjoining room was discarded as a source of electricity. It was replaced by the earth, which had been found to be equally effective, and which has a much greater capacity. The large masses and shield, and when necessary, the injection pin were connected by wire with a copper lightning rod on the outside of the building. This rod formed the ground connection for a steel tower used for wireless. Its top was one hundred feet above the ground. This tower is mounted upon the roof of the physics building, the walls

of which are of red granite. The room containing the apparatus is in the second story of this building, and below this tower.

Twelve copper wires about ten feet in length were soldered to the lower part of the lightning rod, and spread over the ground, their ends being injected a few inches into the soil. The wire leading from the masses within the building to the rod was also soldered to it. Connected with this wire within the room containing the gravitating masses were metal rods surrounding the apparatus on which were hung sheets of metal to which were attached about one thousand pins. Small holes were punched through the metal, the pins were inserted, and the heads were soldered to the metal. This was intended as a means to put all of the air in the room in an electrical condition as near uniform as possible.

With such an apparatus a determination of the gravitation constant would be utterly impossible. The position of the suspended masses changes from day to day and from night to day by greater amounts than was at any time possible when the plate-glass machine was used for electrification of the masses. Their position depends upon the weather and upon the moisture in the surface of the earth. The changes were often greater than was ever caused by the removal or replacing of the large masses. Results obtained on December 12th last are alone sufficient to establish the fact that enormous local changes in the earth's potential are constantly occurring, and that these changes produce variations in gravitational attraction between the large masses and the suspended masses.

On December 5th and 6th over an inch of rain and sleet fell, and on December 8th and 9th there was a light fall of sleet. The minimum temperature gradually fell from 28° on the 5th to 1° on the 10th. The ground was covered with a thin layer of ice and snow on the 12th. On that day the morning temperature was 20° but rose to 56°. The ground around the lightning rod between the build-

ing and a walk about 12 feet from the building was very dry, having been shielded by the building. During the forenoon the large masses and the injection pin for electrification of the air within the shield were connected with the lightning rod. Between 8:50 a. m. and 11:45 p. m. the scale reading decreased very slightly but with no vibrations. The temperature of the air around the shield increased by 1.°5 C. The injection pin was then withdrawn and the glass tube was covered with the metal cap. Vibrations of the suspended masses at once began. The scale reading varied through about three divisions of the scale. This amplitude had diminished to about two divisions of the scale at 1:20 p. m. The time of a complete vibration was about nine minutes. The frozen ground outside of the walk was then covered with a layer of water. Eight buckets of water were splashed over the ground around the lightning rod, covering the area over which the copper wires were spread, this wet area thus formed being finally connected with the wet ground beyond the walk. The scale reading abruptly diminished during the next three vibrations. The change in the average reading was about 80 per cent of the change formerly produced by the removal of the large masses to a position of no deviation in the position of the suspended masses.

This determination of the deviation, due to the large masses, was obtained before electrification of the masses was begun. They were, however, then above the surface of the earth, and subject to the inductive action of the atmosphere.

The results described in this paper indicate that the disturbances here discussed would be greatest if the work were done on a barren island, in a building above the level of the surrounding water. It is under such conditions that the phenomenon known as St. Elmo's fire is commonly observed. On land each blade of grass and the leaves of trees have a function similar to that of the masts of ships provided with lightning protection. They are

individually less effective, but they are far more numerous.

In order to eliminate these disturbing effects the work should be done in a room below the surface of the earth, the walls, ceiling and floor being of metal. Insulated copper wires within copper tubes should be connected with the masses. Those connected with the suspended masses should terminate in a cup of mercury. A flexible chain of metal attached to the middle of the bar carrying the suspended masses, should be provided at its lower end with a fine platinum wire, making contact with the mercury surface. These protected copper wires should be grounded in a well of water. The water in this well must be protected from any inductive action of the atmosphere.

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